

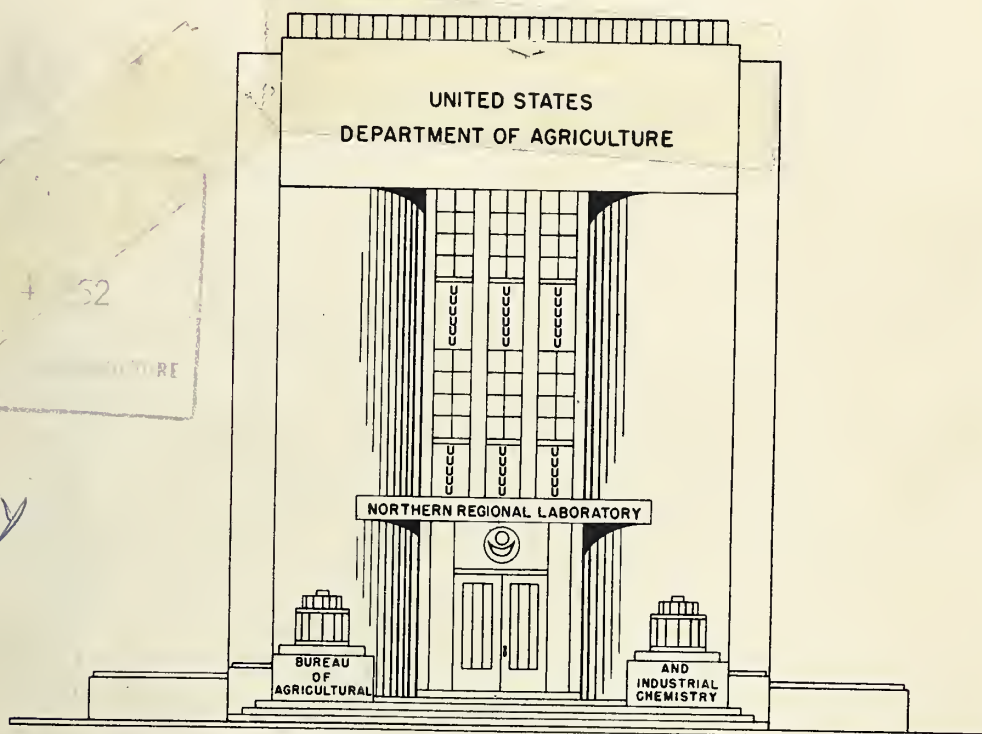
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UNITED STATES DEPARTMENT OF AGRICULTURE
Agricultural Research Administration
Bureau of Agricultural and Industrial Chemistry

DRY GRINDING OF AGRICULTURAL RESIDUES
A NEW INDUSTRIAL ENTERPRISE



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DRY GRINDING OF AGRICULTURAL RESIDUES

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By

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INTRODUCTION

Profitable applications for mechanically processed⁴ agricultural residues have been responsible for the establishment of processing enterprises with benefits to both agriculture and industry. The expense, nuisance, and hazards associated with the accumulation and disposal of these residues on farms, at elevators, and at grain- and food-processing plants have, in turn, been correspondingly reduced. Significant economies and improvements in agricultural and industrial methods have been realized through proper exploitation of the residues. It is estimated that well in excess of 600,000 tons of mechanically processed agricultural residues are now being used each year.

Corncobs, rice hulls, and shells of nuts and fruit pits currently constitute the more important materials from the standpoint of mechanical processing. Straws, stalks, and flax shives, while receiving close attention as raw materials for paper and board manufacture because of their fibrous properties, have also received some minor attention as potential industrial raw materials through mechanical processing.

More than 200 million tons of agricultural residues are produced each year in the United States. Of that quantity about 20 million tons are corncobs. However, only a portion of the cobs becomes available for mechanical processing because of location, problems of collection and transportation, farm uses, and similar factors. This is likewise true for other residues such as nut shells and fruit pits.

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⁴ Mechanical processing denotes cleaning, dry grinding, and classification, with emphasis on the grinding operation.

Properties of Residues of Commercial Value

The acceptance and increased use of mechanically processed agricultural residues by the consuming industries has been achieved not only because of successful merchandising by certain processors but also because of the chemical and physical characteristics of the residues. The significance of these characteristics may be realized through a brief discussion of several of the proven and accepted applications for dry ground or mechanically processed agricultural residues.

The high pentosan content of corncobs, oat hulls, rice hulls, and cottonseed hulls accounts for the use of these residues in the manufacture of furfural. While furfural manufacture was based originally on the use of oat hulls accumulating as a byproduct in the preparation of oat cereals, the increasing demand for furfural necessitated use of other furfural-yielding raw materials. Rice hulls and cottonseed hulls were available in large volume as byproducts from rice mills and cottonseed processing plants, respectively, and have been used. However, because of the value of cottonseed hulls in feedstuffs and of the shipping charges and ash content associated with rice hulls, the two materials have been replaced largely by corncobs. Although corncobs are fairly bulky, approximately 25 tons of whole cobs can be packed into the ordinary railway boxcar for shipment to furfural plants. Car capacity can be increased by crushing the corncobs prior to loading, but furfural manufacturers prefer to do the crushing. Furfural manufacture alone probably accounts for more than 400,000 tons per year of high pentosan-containing residues.

The tannin content of pecan shell septa and liners accounts for the operation of extraction plants for the separation and recovery of tannin from pecan shell refuse accumulating at both shelling and grinding plants. Crushed shells are used with the septa and liners in the leaching vats to overcome the tendency of the lighter material to pack and reduce percolation.

Absorbency, durability, and general physical structure explain the large-scale use of almond shells, peanut shells, and corncobs as litter for poultry houses. It is believed that, in the aggregate, well over 100,000 tons of these materials are being processed industrially each year for such purpose. Litter must be free of dust and chaff, and particles should be no smaller than 1/4 inch in size. While all three of the materials mentioned have good absorbent qualities, the tough, durable character of the corncob favors its use over that of the other materials. When cobs alone are used for litter the maximum size of the particles should not be much greater than 1 inch. Cob litter, because of its absorbency and toughness, may be used with periodic additions of fresh litter to 1 year and until the litter is up to 24 inches deep. Poultry experts, while recognizing the vitamin B₁₂ value of used litter, do not agree on its re-use for small chicks because of infestations and contamination arising from previous use with older chickens (6, 24, 36)⁵.

⁵ Italic numbers in parentheses refer to Literature Cited, page 33.

Absorbency is a characteristic of corncob particles that makes ground cobs, less than 1/8 inch in size, an excellent feed base for impregnation with blackstrap molasses and other nutrients (2, 7, 8, 10). Rations of this type are used regularly by some feeders of beef cattle. The vitamin content of chaff, beeswing, and pith fractions is greater than that in the woody portion⁶ so that it is advantageous to use these components rather than the ground whole cob or the woody ring in feeds. Both oat hulls and rice hulls have been used in mixed feed bases but the use of rice hulls is to be discouraged because of their high silica content, about 20 percent. This silica is abrasive and is considered harmful in the digestive systems of cattle.

The largest industrial use for ground corncobs is also based on characteristics of absorbency, toughness, and abrasion resistance. Metal stampers and electroplaters use large tonnages of ground cobs in removing oils, greases, and plating rinse waters from stampings and electroplated pieces and in polishing these pieces. Most frequently such work is done in tumbling barrels. The composition of the material and the intricacy of the surface of the objects being finished influence the selection of corncob grits both as to particle size and shape.

Corncob particles, as generally used, range in shape from slivers to cubes or grains; they range from No. 10 to No. 60 in size⁷. The tough, grainless structure of cob particles gives cob grits long periods of usefulness for cleaning, drying, and polishing. Fruit pits and nut shells, although lacking the toughness and absorbency of the woody portion of cobs, are used widely in a number of finishing and polishing operations which include flash removal from molded plastics, molded rubber, and metal die castings. The significance of these applications may be realized from a report of one manufacturer of precision instruments (13) to the effect that his firm was saving more than \$100,000 yearly through the use of soft grits (apricot pit shell) in its finishing operations.

Blast cleaning by means of soft grits, prepared from corncobs and shells of fruit pits and nuts, is a rapidly expanding application for processed agricultural residues. Toughness, hardness, density, and resistance to impact and abrasion are characteristics which make cobs and shells suitable for use as grits in this operation. Proper selection of soft grits makes possible the blast cleaning and finishing of metals, plastics, rubber products, glass, and electrical insulation. This application and the characteristics of several soft grits have been discussed by Lathrop and Aronovsky (28) and by Clark and Lathrop (17). One processor of corncobs supplied over 500 tons of soft grits to the Navy during World War II for cleaning aircraft engines. During that same period the Air Force used soft grits from shells of walnuts and apricot pits. Civilian and military use has continued to expand significantly both in manufacture and maintenance. Soft grits ranging in size from No. 10 to No. 50 are available in a variety of physical properties. Although standard air-blast cleaning equipment is entirely satisfactory for this application, some equipment manufacturers have aided the development by making equipment specifically for the use of soft grits. This is particularly true where grits are used in cleaning electric motors and generators.

⁶ Data. Northern Regional Research Laboratory for future publication.

⁷ Size numbers refer to square-mesh woven-wire sieves by which materials are classified. Where the number is shown as a fraction, for example No. 25/40, the material is finer than No. 25 and coarser than No. 40. Standard sieve openings considered as standard according to Federal specifications are shown in table 1.

Fillers, extenders, diluents, and carriers are prepared from a number of agricultural residues and are used in the manufacture of a large variety of materials such as adhesives, insecticides, explosives, soap, plastics, and rubber compounds. Many of the applications require flours finer than No. 80, some as fine as No. 325. As a filler and diluent for explosives the particles may range between No. 10 and No. 100 in size, the individual specifications covering much narrower limits.

Basis for Establishing Residue Processing Plants

The problem of disposing of primary processing residues often provides the necessary incentive for the establishment of dry grinding or mechanical processing plants. Fruit canners, nut shellers, and corn millers are frequently confronted with the hazards and expense associated with the accumulation of fruit pits, nut shells, and corncobs at the plant sites. Mechanical dry processing or grinding of these residues for agricultural and industrial uses has turned such accumulations from hazards and expense into profitable articles of commerce.

In contrast to the problem of disposal, many individuals have had both the foresight and the initiative to invest in dry processing operations in order to establish an independent business. Shortages of materials of similar nature and the superior properties of processed residues have been added inducement for the individual with capital to invest. Agricultural residues, annually replaceable as raw materials, deserve attention also from the standpoint of conservation of other materials less easily replaced.

In considering the mechanical processing of agricultural residues two facts should not be overlooked. First, residues, although frequently a waste and treated as such, cannot be considered as no-cost raw materials; and second, mechanical processing installations, to be effective, involve substantial capital expenditures. Aside from other factors, the success of a dry grinding operation is to some extent proportional to the initial investment.

Previous Engineering Processing Data

Widespread commercial use of mechanically processed agricultural residues is a rather recent development, and little, if any, special engineering information has been available for the construction of plants and effective processing of the residues. A search of publications, reference books, and manufacturers' catalogs disclosed that considerable information was available on the grinding of ores, coal, limestone, spices, and many other substances, but none on the processing of agricultural residues⁸. One

⁸ Zimmerman, O. T., and Lavine, Irvin. CHEMICAL ENGINEERING COSTS. [Grinding of corncobs is mentioned on p. 158.] Industrial Research Service, Dover, N. H. 1950.

Table 1. - *Square openings in woven-wire sieve cloth*¹

U.S. Standard number	Opening	Approximate equivalent	U.S. Standard number	Opening	Approximate equivalent
	<i>Millimeters</i>	<i>Inch</i>		<i>Millimeters</i>	<i>Inch</i>
3-1/2	5.66	0.223	40	0.42	0.0165
4	4.76	.187	45	.35	.0138
5	4.00	.157	50	.297	.0117
6	3.36	.132	60	.250	.0098
7	2.83	.111	70	.210	.0083
8	2.38	.0937	80	.177	.0070
10	2.00	.0787	100	.149	.0059
12	1.68	.0661	120	.125	.0049
14	1.41	.0555	140	.105	.0041
16	1.19	.0469	170	.088	.0035
18	1.00	.0394	200	.074	.0029
20	.84	.0331	230	.062	.0024
25	.71	.0280	270	.053	.0021
30	.59	.0232	325	.044	.0017
35	.50	.0197	400	.037	.0015

¹ Federal Specifications for Sieve; Standard, Testing, RR-S-366a, April 1942.

equipment manufacturer presented with the problem of grinding corncobs considered corncobs so difficult to grind that commercial processing would not be feasible. Consequently, corncob grinding plants were established on a trial-and-error basis and met with many difficulties, needless expense, and disgruntled customers. Although those early grinding plants were not suitable for reliable cost-evaluation studies, sufficient information was gained to indicate that, with study and improved equipment and techniques, successful dry-grinding operations might be achieved. Furthermore, the explosive and fire hazards associated with crushing and grinding these combustible materials, although widely recognized and publicized, had not been given proper attention. Consequently, explosions and fires were frequent, sometimes causing complete destruction of plants and loss of life.

Operational problems were complicated by the general lack of understanding of the physical and chemical characteristics of the agricultural residues as well as of the properties expected in the finished products. This lack of understanding of the problems involved precluded the proper selection of equipment and the right sequence of operational steps. Many tests had been conducted by equipment manufacturers in attempts to evaluate machines but a lack of understanding of the problems by both the manufacturers and their clients hindered the accumulation of complete engineering data. Failure to give consideration to all the factors involved in the operation of grinding prevented correlation of results from individual tests. Adequate attention, for example, was not given to such factors as moisture content of raw materials, particle size distribution, and the nature of the byproducts.

During the time the Northern Laboratory was engaged in studying methods of grinding and was developing uses for agricultural residues, the Tennessee Valley Authority was investigating the processing of black walnut shells to a flour for use in plastics and adhesives (42). This processing study was limited to production of fine flours. It did not attempt to produce materials for soft-grit blast cleaning, burnishing, or polishing. The expense of producing flours, consequently, was greater than if efforts had been directed towards producing a series of merchandizable products.

Principles for Successful Operation

Four basic principles that should be followed to achieve success in utilizing agricultural residues have been cited by Lathrop and Shollenberger (29). In brief, these principles are:

1. Establishing sound economical methods for procurement and preservation of the residue materials.
2. Establishing uses based on superior or unique chemical and physical characteristics of the residues.
3. Avoiding the production of wasteful by products.
4. Maintaining a sound merchandising and business management policy.

These principles have been kept in mind in making the study of mechanically processing agricultural residues at the Northern Regional Research Laboratory. Active participation of the Laboratory on this problem has followed numerous requests for aid and information by individuals attempting to process residues and by those seeking an answer to their residue disposal problems. The studies were also in accord with other objectives of the Laboratory to develop and promote the use of agricultural residues with benefits to both agriculture and industry.

RESIDUES USED IN DRY PROCESSING

Availability

Agricultural residues of some description are available in every State and Territory, although in some instances concentrations of specific residues are too low to allow their consideration for practical commercial processing. Harvesting of crops is strictly seasonal and in many cases the products must be processed or packed promptly during the harvest period, with the result that large quantities of the residues accumulate within a short time. This is particularly true of fruit pits. Processing of other crops may be delayed and their residues can be stored for continuous processing throughout the year. Nut shells, for example, accumulate from year-round processing or shelling operations. Corncobs occupy a somewhat intermediate position. A major portion of the corn crop is shelled in the late fall and early winter and the remainder is stored as earcorn for later shelling. Dunning, *et al.* (21) have reported that approximately 60 percent of the corncobs from shelling operations are available from October through January, the remaining 40 percent being available throughout the remainder of the year, with an appreciable increase about April when spring shelling is in progress.

Surveys conducted by the Northern Laboratory show that ample supplies of agricultural residues for commercial processing exist over a considerable area. The areas in which corncobs accumulate in quantity are illustrated in figure 1. Corncobs available during 1950 from corn harvested for grain is shown by States in table 2. Significant quantities of fruit pits or nut shells are available in California, Oregon, Washington, Texas, Virginia, Oklahoma, Arkansas, Missouri, Louisiana, Tennessee, Michigan, and Georgia.

An area in which a mechanical processing plant is to be located must be capable of furnishing a minimum of 5,000 tons per year of a given agricultural residue within a definite transportation radius. This radius is influenced by a number of factors, such as the physical character of the residue, the value of the finished products, and the costs of the residue, of transportation, and of processing.

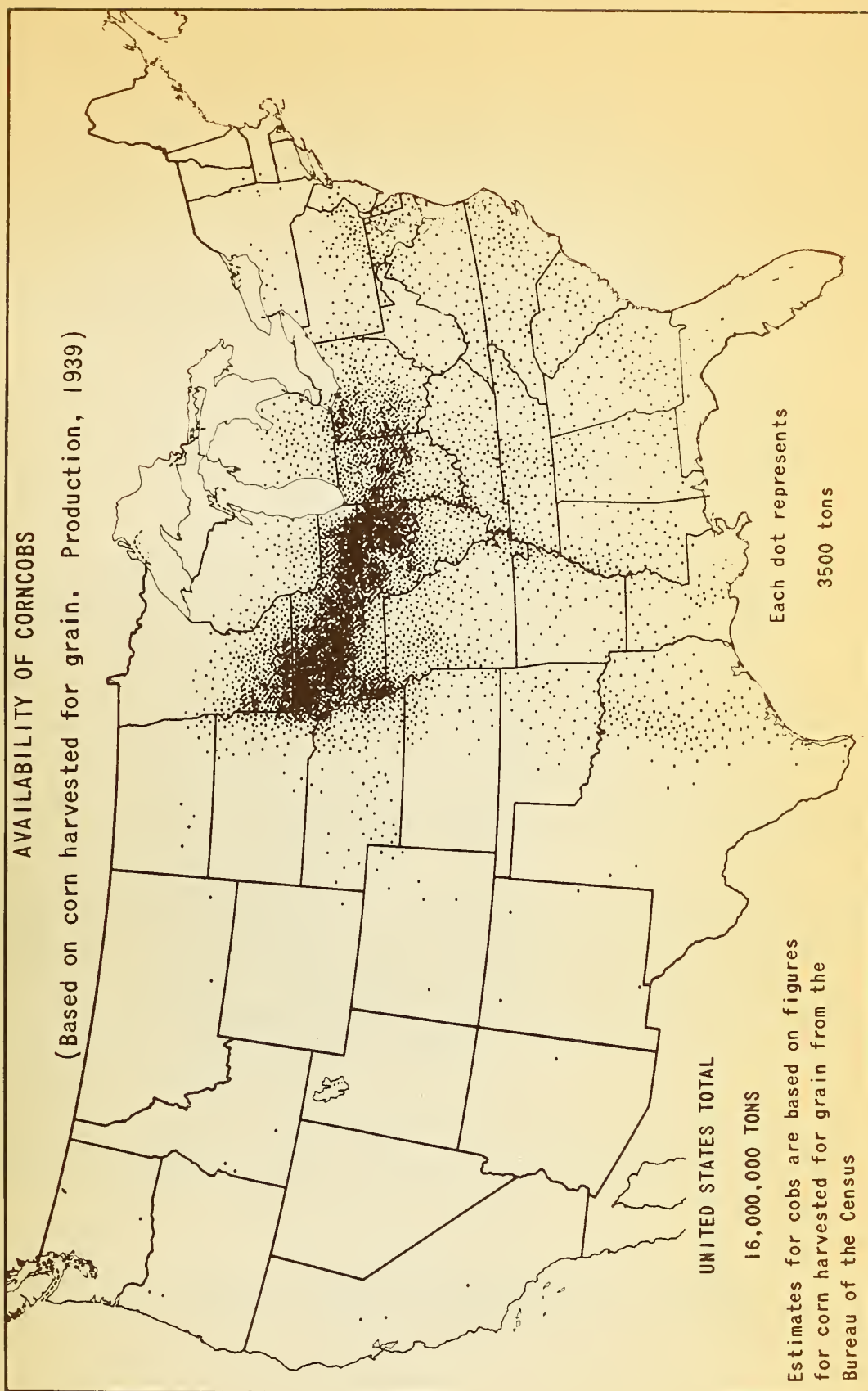


Figure 1. - In the Corn Belt, the area shown as nearly black on the map, the corncobs exceed 21 tons per square mile and in some counties rise to 35 tons per square mile

Table 2. *Available corncobs by States. 1950*¹

State	Tons	State	Tons
Ala.	315,144	Nebr.	1,449,360
Ariz.	2,250	Nev.	-
Ark.	188,520	N.H.	576
Calif.	9,576	N.J.	39,204
Colo.	50,424	N. Mex	6,036
Conn	1,620	N.Y.	49,950
Del.	29,868	N.C.	428,274
Fla.	31,920	N. Dak.	56,100
Ga.	249,984	Ohio	984,360
Idaho	5,778	Okl.	142,548
Ill.	2,450,448	Oreg.	2,490
Ind.	1,230,060	Pa.	285,138
Iowa	2,734,236	R.I.	258
Kans.	512,820	S.C.	180,984
Ky.	461,760	S. Dak.	525,672
La.	99,288	Tenn.	397,020
Maine	408	Tex.	341,760
Md.	99,528	Utah	1,080
Mass.	1,260	Vt.	864
Mich.	291,798	Va.	248,124
Minn.	921,696	Wash.	2,640
Miss.	304,278	W. Va.	49,062
Mo.	1,014,552	Wis.	359,904
Mont.	1,800	Wyo.	1,824
		Total	16,562,244

¹ From corn harvested for grain. Calculated from data published by U.S. Dept. Agr., Bur. Agr. Econ. Crop Reporting Board(5). A bushel of corn represents approximately 12 pounds of cobs.

Physical and Chemical Characteristics

Agricultural residues display such a variety of shapes, sizes, and other physical characteristics that it is necessary to consider these materials in groups of similar nature.

The shells of nuts and fruit pits, in general, are hard, woody substances having outer surfaces varying from smooth to very rough. The outer surfaces, particularly those of fruit pits and the rough nut shells, may have residual flesh, fibers, or hull material attached. The interior of the nuts or fruit pits may, in addition to the kernels, contain paper-like liners and septa, or spongy, cork-like lining materials. Others may contain paper-like coverings over the kernels that loosen during the shelling operations and become included with the shell fragments. Fruit-pit shells may be available as half-shells as the result of a cutting operation during canning of fruit. Some shell pieces, such as those of coconuts, may be 3 to 4 inches or more in one dimension.

Corncoobs, ranging from nearly cylindrical to almost conical in shape, are generally 7 to 10 inches long, 1 to 1 3/8 inches in diameter at the butt, and taper to about 3/4 inch near the tip. White cobs are frequently larger in diameter than red cobs. Corncoobs run about 10 to 14 pounds per bushel of shelled corn. In this discussion 12 pounds of cobs to the bushel of hybrid corn is assumed as average. Structurally, the cob may be divided into four parts: (a) Fine chaff, or beeswing; (b) coarse chaff; (c) woody ring at the base of the glumes; and (d) pith. The woody ring is extremely hard and tough and relatively resistant to both abrasion and granulation. It is this portion of the cob that has proved most important for industrial uses. The proportions in which the structural components of corncoobs occur are presented in table 3. A detailed account of the structure of several varieties of corncoobs is given in a report by Lenz (30).

Straws, stalks, shives, hurds, and some seed hulls may be considered as a group. With the exception of the hulls, these materials generally contain long fibers and may range in size from a few inches to more than a foot in length and from 1/4 to about 1 inch in diameter. Stalks such as from corn, small grain, and sugarcane may be several feet long. The fibrous portion comprising the outer wall structure frequently covers a core of pith. The hulls are often similar in structure to the wall structure of the straws but are composed of shorter fibers and contain no pith.

Chemically the agricultural residues possess a high degree of similarity; for example, all are composed of pentosans, lignin, and cellulose, and minor amounts of other materials. In general, the proximate composition is much the same, the most notable exceptions being in pentosan content. The higher pentosan content of oat hulls, corncoobs, cottonseed hulls, and rice hulls accounts for their use in the manufacture of furfural by acid hydrolysis. Analytical data pertaining to straws, stalks, hulls, cobs, and shells have been presented by Clark and Aronovsky (16), Nelson, *et al.* (33), and Lathrop and Shollenberger (29). A portion of these data is presented in table 4. The similarity in composition of the structural components of corncoobs is shown by data presented in table 5.

Procurement and Storage

The seasonal availability of most agricultural residues has a profound influence on the manner of collection or procurement and storage. Likewise, the general climatic conditions of an area are influencing factors. Canneries, shelling plants, and corn-milling plants are excellent accumulation points of some residues. In the case of fruit pits from canneries, the pits must be collected during the canning season. Because of the high bulk density of the pits and the value of the kernels, it is possible to collect and transport fruit pits by rail over considerable distances from the shell processing plants. The collection problem for cobs is somewhat similar because, as previously mentioned, a higher percentage of the cobs are available in the late fall and early winter and, of course, must be collected at that time. The low bulk density as well as the lower value of cobs limits the radius over which cobs may be collected by truck for a given processing plant. This radius is usually 25 to 30 miles.

Cracking plants for the shelling of nuts usually operate throughout the year, and the shells accumulate regularly. Often a mechanical processing plant may be established in conjunction with shelling operations so that storage of shells does not become a problem. Shell storage in this case should be sufficient to provide an adequate quantity of shells during periods when shelling operations are interrupted. Storage must be provided for shells which are acquired from cracking operations at other locations.

The problem of storing corncobs has been investigated by Dunning, *et al.* (21) who reported that, even with storage in the open, deterioration is negligible up to 6 months and does not become appreciable until after 12 months of exposure. In their investigation, cob piles were examined at 6-inch intervals to a depth of 42 inches. Approximately 30,000 tons of cobs were sampled in their investigation.

Satisfactory shelter, figure 2, may be provided for corncobs by specially constructed storage sheds. These sheds consist of a sheet metal roof and sidewalls formed by heavy wire or snow fencing supported by timber placed in an upright position from ground to roof. In this way the open sidewalls allow air to circulate through the cobs as an aid in drying. Ventilated storage allows for reduction of moisture in cobs from 25 to 15 percent in 3 to 4 months. Removal of husks and fines from the cobs before storing accelerates drying. Crushing of cobs before storage, although accelerating drying and permitting storage of larger quantities of cob material, is not advisable because the dense packing prevents circulation of air and favors mold growth which in turn will cause heating of the cobs. Fires supposedly resulting from dense packing have been reported. These are rare, although temperatures as high as 150° F. have been observed in piles of densely packed moist cobs (21).

Table 3.-*Weight and proportions of cob fractions*¹

Item	Weight	Proportion of cob
	<i>Grams</i>	<i>Percent</i>
Cob, whole	46.3	100.0
Cob, fractions:		
Woody ring	27.9	60.3
Coarse chaff	15.6	33.7
Fine chaff	1.9	4.1
Pith	.9	1.9

¹ Air-dry basis, approximately 12 percent moisture.

Analysis by Commodity Development Division, Northern Regional Research Laboratory, on one cob, about normal size, of Illinois 972 hybrid corn. Length of cob, 8.4 inches; diameter at mid-section 1.19 inches, at butt 1.15 inches. The separations were made by hand.

Table 4. Proximate analyses of several agricultural residues¹

Material	Solubility in constituents										Alpha-cellulose in			
	Hot water	One percent sodium hydroxide	Hot water	One percent sodium hydroxide	Acetone	Nitrogen	Pentosans	Cutin	Lignin	Ash	Cross	Monoethanolamine	method	
Almond shell, soft shell	11.9	27.9	2.6	3.9	0.32		31.0	0.0	24.9	3.1	23.3	22.9		
hard shell	4.4	17.8	4.2	2.4	0.19		34.2	0.4	27.1	1.0	24.2	23.6		
Apricot pit shell	2.1	14.1	1.1	1.3	0.12		32.8	0.9	30.1	0.7	24.6	27.2		
Bagasse	-	-	0.37	-	-		30.0	-	20.5	3.0	-	-		
Coconut shell	3.3	22.0	3.0	3.7	0.12		31.6	0.3	33.9	0.7	26.1	24.3		
Corn cobs	-	-	1.27	-	-		38.9	-	12.5	1.67	-	-		
Corn stalks	-	-	18.7	-	-		24.4	-	15.7	4.1	-	-		
Corn stover	-	-	12.9	-	-		26.0	-	12.6	8.1	-	-		
Filbert shell	2.2	13.3	1.8	1.8	0.16		29.4	10.0	34.5	0.7	-	25.8		
Flax shives	-	-	3.9	-	-		26.6	-	24.9	3.9	-	-		
Peach pit shell	2.3	14.8	1.5	1.7	0.15		31.1	1.7	37.2	0.4	20.5	22.6		
Pecan shell	7.8	25.5	1.1	1.9	0.24		26.0	0.5	45.7	1.8	17.7	19.7		
Rice hull	7.8	45.2	3.5	3.4	0.46		26.0	2.2	19.2	22.6	-	28.2		
Walnut, Black	2.5	13.7	1.9	1.5	0.20		28.3	12.7	30.8	0.3	26.2	28.1		
English	3.5	18.5	1.1	3.2	0.17		29.5	0.7	38.0	0.8	24.8	25.2		
Wheat straw	-	-	1.9	-	-		31.2	-	14.7	8.9	-	-		

¹ Values previously reported by Clark and Aronovsky (6) and Nelson, et al (7).



Figure 2. - A satisfactory type of cob storage shed. Open sides are made of timber uprights and snow-fence sidewalls backed by horizontal slats. Heavy cable is used for cross braces.

Table 5.- Analytical data pertaining to the structural parts of the cob--fine chaff, coarse chaff, woody ring, and pith¹

Determination	Structural part			
	Fine chaff	Coarse chaff	Woody ring	Pith
	Percent	Percent	Percent	Percent
Ash	1.39	1.26	1.16	1.46
Soluble in 1% sodium hydroxide	52.3	42.0	48.0	46.2
Soluble in hot water	7.8	7.2	9.5	10.7
Soluble in ether	1.3	.8	.9	1.9
Soluble in alcohol-benzene, 7 hours	3.3	6.1	9.0	9.3
Soluble in alcohol-benzene, 20 hours	4.4	7.0	9.5	9.4
Pentosans	34.2	37.4	39.2	34.5
Furfural	20.0	21.8	23.0	20.1
Lignin, crude ²	11.3	11.8	9.1	10.0
Nitrogen	.67	.34	.26	.25
cellulose, Cross and Bevan, ash-free	49.4	59.8	58.1	56.7

¹ Moisture-free basis.

² The lignin may be corrected for ash by subtracting 0.2 from the true lignin figures.

Analyses by Analytical and Physical Chemical Division, Northern Regional Research Laboratory, of hand-separated components, or parts, of cobs of the corn variety Illinois Hybrid 972 grown near Wyoming, Ill., in 1940.

MECHANICAL PROCESSING EQUIPMENT--DESCRIPTION AND OPERATION

Mechanical processing of agricultural residues is not limited to crushing, grinding and classification only; it involves many operations extending from their procurement or receipt at a processing plant to shipping of products to consumers. These operations include various methods of cleaning, conveying, drying, dust collecting, and others which are given consideration throughout the following discussions.

Raw Material Cleaning and Conveying

Because of conditions associated with their accumulation, many of the residues require extensive cleaning operations to remove contaminants, components unique to specific residues, and residual materials from prior processing. Iron and steel may be removed by magnets placed at strategic points in a mechanical processing system. Stones and pieces of wood and similar materials can be removed through use of screens and aspiration. Equipment for this purpose is obtainable and manufacturers should be consulted for engineering data and specifications. Cleaning or removal of contaminants may be combined with pneumatic conveying. With this method separation takes place because of differences in density or the weight of individual particles. Conveying of the raw materials from a receiving dump or pit may also be accomplished through the use of bucket elevators, and belt or screw conveyors. Cleated belt conveyors are economical but may be of limited value in installations where elevating to considerable height is necessary and where space is at a premium. Bucket elevators and screw lifts are very useful in confined quarters. Conveyors using high frequency vibrations are available, and may be used for cleaning raw materials.

Removal of undesirable components from the raw material may take place before the raw materials are placed in storage. These components may include husks, nut meat fragments, fruit pulps, pit kernels, shell liners, septa, and residual grain. The method for their separation and removal is dependent upon the residue involved. With corncobs, considerable quantities of husks and even grain may be attached to the cob. Certain types of shellers, having a series of bars over which the cobs rub, are effective in removing not only the residual grain and husks but also a substantial portion of the beeswing and chaff. Markets for baled husks as feed and as an industrial filtering medium have been established. Thus, cleaning may extend the number of salable products as well as improve the quality of the principal products.

Crushing and Grinding

Selection of proper crushing and grinding equipment is influenced by several factors:

1. Physical properties of the original material.
2. Size, both of the feed⁹ material to the grinding mill and of the product.
3. Capacity required.
4. Physical properties, other than size, required in the product.

The first three factors as applied to crushing and grinding have been ably discussed by Walker, Lewis and McAdams (38). The fourth factor increases in importance with the heterogeneous structure of the feed material, with the physical properties possible in the products, and with the intended use of the products. For example, with corncobs consideration of the fourth factor becomes very important. Because the structural components of the cob differ considerably in physical properties, these components respond differently to various grinding treatments. As will be shown later, the physical characteristics of ground cob products, particularly those from the woody ring, can be controlled by the manner of crushing, grinding, fractionating, and classifying.

Equipment for crushing and grinding has been classified rather loosely as: (a) Coarse crushers; (b) intermediate crushers; (c) fine grinders; and (d) fine pulverizers. This classification allows for overlapping of characteristics with respect not only to the size of feed handled but also to the size and physical characteristics of the end products. The equipment which will be discussed includes various modifications of rotary knife cutters, roll crushers, cone crushers, roller mills, ball mills, attrition mills, buhr mills, buhrstone mills, hammer mills, and bowl or roll pulverizers.

COARSE CRUSHING

Roll Crushers.--The term "roll crusher" is somewhat misleading in that the so-called rolls are actually rotors carrying very coarse teeth or lugs. One or two rotors mounted horizontally operate within an enclosure which also may have fixed

⁹ The term "feed" as used in this discussion denotes unprocessed or semi-processed material that is *charged or introduced into grinding equipment for further reduction.*

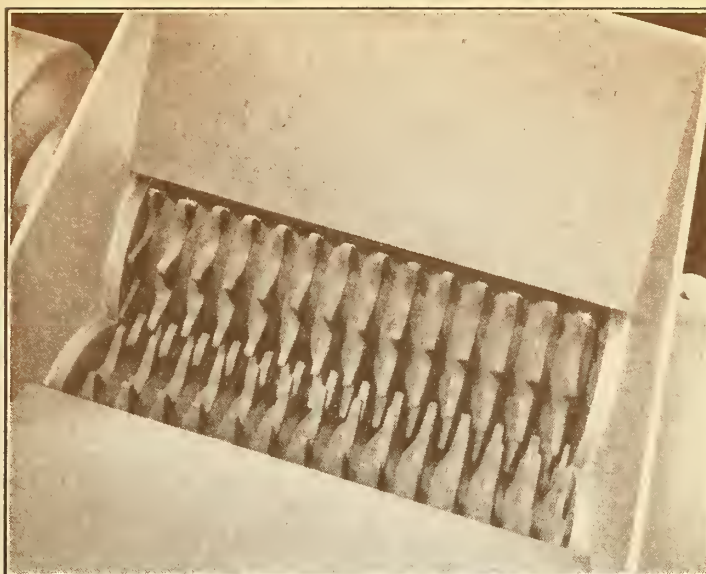


Figure 3. - "Roll crusher": an interior view showing the arrangement of the teeth.

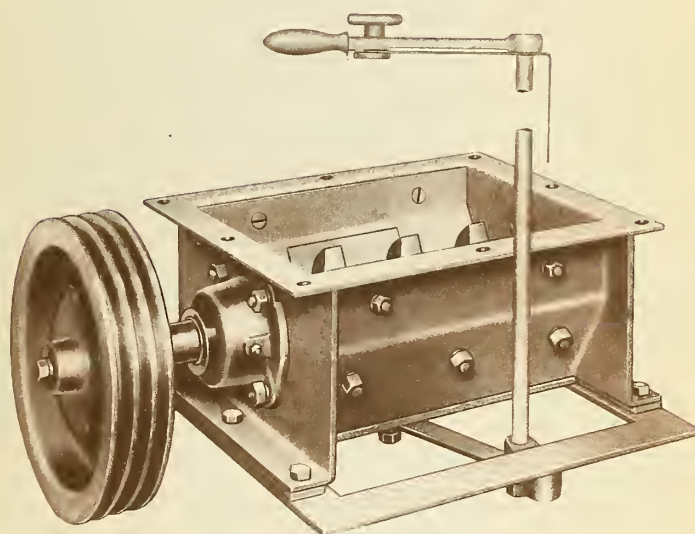


Figure 4. - A typical crusher feeder.

Table 6.- Operating characteristics of a cone type ear-corn crusher breaking whole corncobs¹

Run No.	Capacity of crusher	Power used	Crushing rate	Product distribution			
				Percent	Percent	Percent	Percent
				Total material passing through sieves indicated. All passed 7/8 inch.			
				7/16 in.	No. 3 1/2	No. 12	
Cone in open position							
	Lb./hr.	Hp.	Lb./Hp.hr.	Percent	Percent	Percent	Percent
1	750	5.5	137	44.6	6.5	2.5	
2	1,000	5.2	192	34.9	6.2	1.9	
3	1,250	6.6	189	53.6	11.1	3.5	
4	1,500	8.0	188	59.3	14.2	4.1	
5	1,750	10.5	167	57.0	13.5	4.7	
Cone in closed position							
6	1,500	8.6	175	60.0	13.9	4.6	
7	1,750	11.1	157	56.3	13.3	4.3	
8	2,000	14.6	137	67.8	17.1	5.9	
9	2,400	14.8	163	66.7	15.9	5.8	

¹ Cone speed, 187 1/2 r.p.m. Moisture content of corncobs, 12.3 percent. Crusher powered by a 15 hp. motor. Power required to operate empty crusher: cone open, 1.6 hp.; cone closed, 2.4 hp.

teeth. Material passed into the crusher is broken between adjacent teeth on the rotor and the fixed teeth. Tooth arrangement is illustrated in figure 3. A heavy perforated plate or moving bars may be provided below the rotors to restrain movement of material until it has been reduced to the proper size. The size of the product from this equipment varies with the size and spacing of the teeth as well as the size of openings below the rotors. The crushing rate of these units is usually very high for the horsepower input. This type of equipment can also be used as a feed regulating device to other grinding equipment. A typical crusher feeder is shown in figure 4. It has been advertised that units of this type with 7 1/2 horsepower drives have high capacity when handling ear corn, although no factual data are as yet available on their performance in processing corn cobs.

Cone Crushers. -- Two conical sections comprise the working elements of this type of crusher. One section that rotates about a vertical shaft is enclosed by a second conical section which is hollow and fixed. The outer surface of the inner section and the inner surface of the outer shell carry coarse corrugations between which materials are crushed or broken. Particle size of the products is controlled within limits by the clearance between the corrugated surfaces. Modifications of the cone crusher include units in which the outer section is inverted with respect to the rotating section so that larger pieces of feed material can be reduced. The shaft carrying the inner section may be mounted in an eccentric bearing to provide increased crushing action above that possible by rotation alone. A sectional view of a typical cone crusher is shown in figure 5.

One cone crusher investigated was an ear-corn crusher used for crushing whole corn cobs during the semi-works scale production of liquid fuels from agricultural residues (1). Particle size of the product was controlled by vertical adjustment of the inner cone. In the studies at the Northern Laboratory tests were conducted with the inner cone in two positions; fully raised and completely lowered. Feed rates for whole corn cobs fed to the crusher were maintained at constant values ranging from 750 pounds per hour to 2,400 pounds per hour. Operating characteristics of this crusher and the character of the crushed cobs are shown in table 6. Continuous operation of this unit in semi-works processing of corn cobs disclosed that under the dust condition encountered the exposed ring and pinion drive proved to be subject to excessive wear. Proper design of the driving mechanism is, therefore, very important for economical maintenance of such crushers.

Hammer Mills. -- The hammer mill may be considered both as a coarse crusher and as an intermediate grinder. Hammer mills are essentially impact crushers; swinging bars or hammers of various descriptions attached to a rotor turning at high speed shatter the materials by impact against breaker plates. Breaker plates and perforated screen form the enclosure within which the rotor turns. The perforated screen controls product size by retaining material within the mill case until the particles are small enough to pass through the perforations. The rotor carrying the hammers may be vertical or horizontal. Materials discharged from the hammer mill may be collected and conveyed by means of a blower, integral with the mill, or arranged to be operated separately. The essential parts of a hammer mill are shown in the sectional drawing, figure 6.

Crushing whole corn cobs in a hammer mill is rather common practice in cob processing plants and country grain elevators. However, more efficient operation is

obtained by precrushing corncobs in a roll crusher first. This practice eliminates surges and shock loading of the hammer mills and prolongs life of hammer-mill screens.

The number and type of variables associated with hammer mill operation make it possible to obtain closer control over the product than is possible with the cone crusher. Size and shape of screen perforations; size, shape, and number of hammers; and rotor speed have a pronounced influence on the character of the product. Furthermore, a wider variety of agricultural residues may be processed in the hammer mill.

A production size hammer mill (12 inches wide, 21 1/2 inches in diameter) used for the same purpose as the cone crusher already discussed has been investigated. Perforations in the screens used ranged from 3/4-inch to 1 1/8-inch diameter so that the cob products would be suitable for use in liquid fuels studies. Feed rates were maintained at values from 740 pounds to 2,600 pounds per hour. With screen openings of 3/4-inch diameter, the number of hammers was varied from 2 to 12. Results of crushing tests are shown in table 7. When a screen having 1 1/8-inch diameter perforations and when two hammers were used on the rotor, the crushed cob product was comparable in characteristics to that obtained with the cone crusher at essentially the same crushing rate. A decrease in size of screen openings to 3/4-inch diameter resulted in a greater amount of product finer than 7/16 inch at a more favorable crushing rate. The amount of material passing a No. 3 1/2 sieve increased about 50 percent without an excessive increase in products finer than No. 12. Increasing the number of hammers in the mill increased the amount of product finer than 7/16 inch but the efficiency of power usage decreased. On the basis of these results, the hammer mill is more effective than the cone crusher for breaking whole corncobs.

INTERMEDIATE CRUSHING OR GRINDING

There is no sharp line of demarcation among machines that may be considered as coarse, intermediate, or fine grinders. Thus, two types of machines already considered as coarse crushers also appear in the discussion of intermediate grinders.

Hammer Mill.--For intermediate grinding the size of screen perforations may be as small as 1/64 inch. However, the characteristics of the material being processed may be the limiting factor with respect to fineness of screen perforations. Shells of fruit pits and nuts may choke or blind the screens, while materials such as corncobs may be so compacted by the impact action that the particles cannot be reduced sufficiently to pass the screen perforations. When corncobs are compacted to small balls or pellets ("buckshot") they become extremely difficult to reduce further and lose their usefulness as a commercial product.

In a series of studies made with whole corncobs and a pilot-plant size heavy duty hammer mill (6 1/2-inch width by 10-inch diameter), the effect of moisture content of the whole cobs, the size of screen perforations, and the number of hammers with respect to power consumption, grinding rate, and particle sizes in the product was determined. Moisture content of the whole corncobs ranged from 17.6 down to 3.3 percent; the diameters of the screen perforations ranged from 1 inch down to 1/4 inch. In one

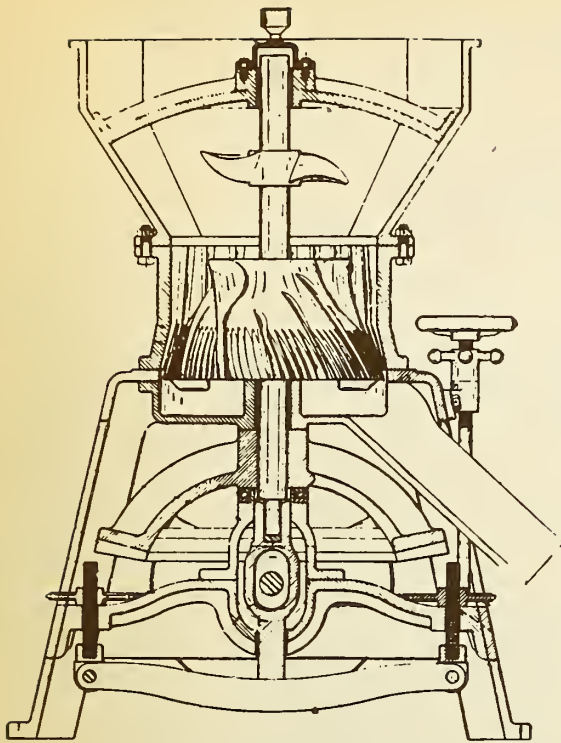


Figure 5. - Cone crusher: a sectional view showing the fixed and rotating sections and the adjusting mechanism.

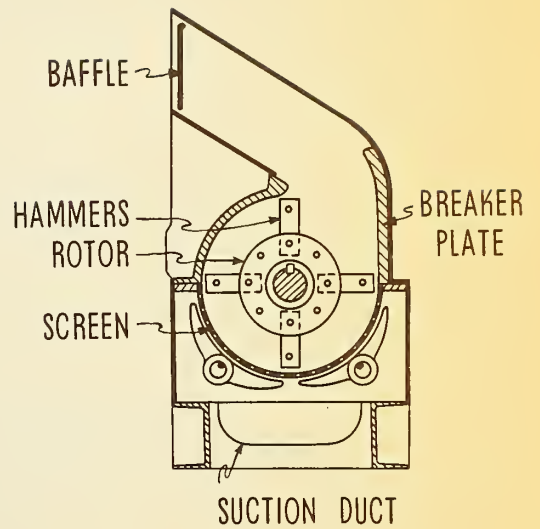


Figure 6. - A sectional view showing the essential parts of a typical hammer mill.

Table 7.- Operating characteristics of a 12 x 24 1/2-inch hammer mill breaking whole corncobs

Run No.	Mill screen. Diameter of openings	Capacity of mill	Power used ¹	Crushing rate	Product distribution		
					Total material passing through sieves indicated		
					7/16 in.	No. 3 1/2	No. 12
					Percent	Percent	Percent
1	3/4	740	8.5	88	91.1	21.9	3.1
2	3/4	970	9.3	104	89.5	20.4	3.3
3	3/4	1,320	10.6	125	87.5	19.1	4.2
4	3/4	1,450	9.6	151	85.7	21.1	4.4
5	3/4	2,050	11.3	185	88.5	20.5	4.6
6	3/4	2,260	12.7	178	84.8	18.6	3.4
7	3/4	2,600	20.1	130	82.6	22.3	5.5
8	1	1,950	11.4	171	70.4	16.1	3.8
9	1 1/8	1,920	11.5	167	64.2	14.8	3.7
10 ²	3/4	1,750	17.3	101	97.8	37.1	5.5
11 ³	3/4	1,990	18.1	110	97.6	39.2	5.5

¹ No-load power requirements: Runs 1 through 9, 5.6 hp.
Runs 10 and 11, 6.4 hp.

² Six hammers in mill, two rows of three each.

³ Twelve hammers in mill, four rows of three each.

Moisture content of corncobs, 12.1 percent. Only 2 hammers used in the mill. Mill powered by 15 hp. motor.

Table 8.- Operating characteristics of a 6 1/2 x 10-inch hammer mill breaking and grinding whole corn cobs, showing the effect of moisture content, number of hammers, and size of screen perforations

Run No.	Moisture content of cobs	Screen openings, diameter ¹	Numbers of hammers used ²	Capacity of mill	Power used	Grinding rate	Total material passing through sieves indicated. All passed 7/16 inch.	Particle distribution
				Lb./hr.	Hp.	Lb./hp.-hr.	Percent	Percent
1	11.1	1	66	965	8.6	113	17.9	3.4
2	11.1	1	66	910	9.1	100	16.2	3.7
3	11.1	3/4	66	857	8.9	97	19.2	5.2
4	11.1	5/8	66	891	10.0	89	20.4	5.2
5	11.1	1/2	66	495	10.5	47	24.6	7.0
6	12.6	3/8	66	222	8.9	25	24.0	7.3
7	17.6	1/2	66	416	10.1	41	17.6	5.4
8	17.6	1/4	66	88	10.1	8.8	37.7	9.1
9	15.3	1/2	33	449	9.4	48	24.7	5.8
10	15.3	5/8	33	645	9.7	67	15.2	3.3
11	15.3	1	33	976	9.9	98	15.2	3.8
12	3.3	1	33	1,663	9.4	177	29.0	5.8
13	3.3	5/8	33	1,262	9.1	138	31.8	10.7
14	3.3	1/2	33	895	9.4	95	36.8	12.9
15	3.3	1/4	33	250	9.3	27	51.1	20.7

¹ Total open area of screens:

Screen size	Total area
1 3/4 inch	28.3 sq. in.
5/8 "	31.8 "
1/2 "	34.4 "
3/8 "	28.0 "
1/4 "	27.8 "
	25.8 "

² Hammers: bar type, 5/16 inch thick, 1 1/2 inch wide, 3 3/16 inch long.

Hammer mill was powered by a 10-hp. motor. Power required to operate empty mill: 3.75 hp.

Table 9.- Operating characteristics of two hammer mills in grinding several agricultural residues

Type of agricultural residue	Screen openings, diameter	Capacity : : : : : :	Grinding rate : : : : : :	Total material passing sieves indicated						Soft grits, blasting
				No. 12	No. 20	No. 30	No. 100	: : : : : :	: : : : : :	
	Inch	Lb./hr.	Hp.	Lb./hp.-hr.	Percent	Percent	Percent	Percent	Percent	Percent
Almond shell, hard	3/16	730	7.8	94	68.9	-	26.9	6.5	42.0	
Almond shell, soft	3/16	600	5.9	100	81.3	-	45.9	10.3	35.4	
Apricot pit shell	1/2	1,980	9.2	216	10.1	-	7.3	-	2.8	
	3/16	228	8.7	26	44.8	-	17.2	6.3	27.6	
Black walnut shell	1/4	4,050*	58	71	78.4	-	37.4	15.2	-	
	3/16	210	8.6	24	50.9	-	22.6	6.9	28.3	
Coconut shell	1/8	284	8.9	32	69.2	17.1	13.4	8.4	27.3	
Corn cobs	1/2	3,340*	55	60.7	17.2(14)	-	7.2	-	-	
	5/16	3,570*	60	60	72.1(14)	-	11.9	3.3(80)	-	
	1/2	450	9.4	48	24.7	-	5.8	-	-	
Corn stover	1/8, 1/64	1,180*	30.3	39.3	-	99.4	-	47.3	-	
English walnut shell	1/4	7,770*	60	130	-	21.5	12.6	-	-	
	1/8	150	8.3	18	68.4	-	16.3	-	52.1	
Filbert shell	1/8	273	8.3	33	75.9	-	27.6	21.5	48.3	
Flax shives	1/64	740*	60	12.3	-	100.0	-	48.6	-	
Hemp hurds	1/8	1,950*	25	78	-	83.9	-	9.0	-	
	3/8, 1/64	830*	60	14	-	99.6	-	54.1	-	
Peach pit shell	3/16	330	8.5	39	56.5	-	22.5	-	33.9	
Pecan shell	1/4	7,900*	60	131	-	-	40.5	26.1	-	
	3/16	495	6.4	77	45.4	-	20.2	16.9	25.4	
	1/8	3,640*	60	61	74.4(14)	47.8	-	16.0	-	
	1/16	1,320*	65	20	95.0(14)	74.2	-	15.4	-	
Wheat straw	3/8, 1/64	665*	50	13	-	99.4	-	58.4	-	

Asterisks indicate a 15 x 24-inch mill, otherwise the size is 6 1/2 x 10 inches. Numbers in parentheses show sieve size where this differs from that shown in column heading.

phase of the investigation the full number of hammers (66 hammers, 5/16 inch thick, 1 1/2 inches wide, and 3 3/16 inches long) was used, while in another series, one-half the number of the same hammers was used. Results of this investigation are presented in table 8. Mill capacity was reduced as the size of the screen perforations was reduced, although some variation resulted from differences in the total open areas of the various screens used. Most significant was the effect of moisture content of whole corncobs on power consumption, mill capacity, and grinding rate. As shown in the table, when a screen having 1/2-inch diameter perforations was used the capacity and grinding rate for corncobs with 3.3 percent moisture were 895 pounds per hour and 95 pounds per horsepower-hour, respectively, as compared to 449 pounds per hour and 48 pounds per horsepower-hour for corncobs with 15.3 percent moisture. In both cases 33 hammers were used. Thus, an increase of 12 percent in this range of moisture content accounted for a decrease in both capacity and grinding rate of about 50 percent. When corncobs of 17.3 percent moisture content were used and the screen perforations were 1/4 inch in diameter the grinding capacity and rate dropped to 88 pounds per hour and 8.8 pounds per horsepower-hour, respectively. Under these conditions "buckshot" or pellets were formed and eventually filled the mill case, necessitating termination of operations. Consideration of power cost, capital for equipment, product characteristics, and plant capacity will aid in determining the advisability of drying whole corncobs before grinding.

Results obtained in grinding a variety of agricultural residues in a 6-1/2-inch by 10-inch hammer mill and a 15-inch by 24-inch hammer mill are presented in table 9. It will be observed that the efficiency, as judged by the grinding rates in pounds per horsepower-hour, is greater for the larger mill than for the smaller mill. For example, when grinding whole cobs of approximately 15.4 percent moisture with screens of 1/2 inch diameter perforations, the grinding rate is 60.7 pounds per horsepower-hour for the larger mill but only 48 pounds per horsepower-hour for the smaller mill. Similar trends may be noted also in grinding pecan shells when screens of 1/8 inch diameter perforations are used. Several factors, such as throat size, effective screen area, and no-load power requirements of the mills, combine to influence the over-all efficiencies.

Attrition Mills.--The attrition mill consists basically of two runners or discs each mounted on an independent shaft and rotating at relatively high speed about a common center but in opposite directions. On the face of each disc is mounted a grinding plate. Mills may be driven by direct-connected motors or through sheaves and belts. The single disc mill is a modification of the double disc mill in that one plate is stationary or fixed so that only one disc rotates. Materials to be ground are fed into the mills at the center throat of one grinding plate and pass through the open space between the plates, finally being discharged at the periphery or outer edges. A wide variety of plate patterns are available so that grinding can be accomplished in accordance with the physical characteristics of the feed and of those required in the product. The size of the product is determined by several factors which include particle size, rate of feed, plate pattern, and plate clearance. Double- and single-disc attrition mills usually are constructed so that the shafting is horizontal. A few machines operate with the shafts vertical. External and cutaway views of horizontal double-disc attrition mills are shown in figures 7 and 8. The single-disc type is illustrated in figure 9.

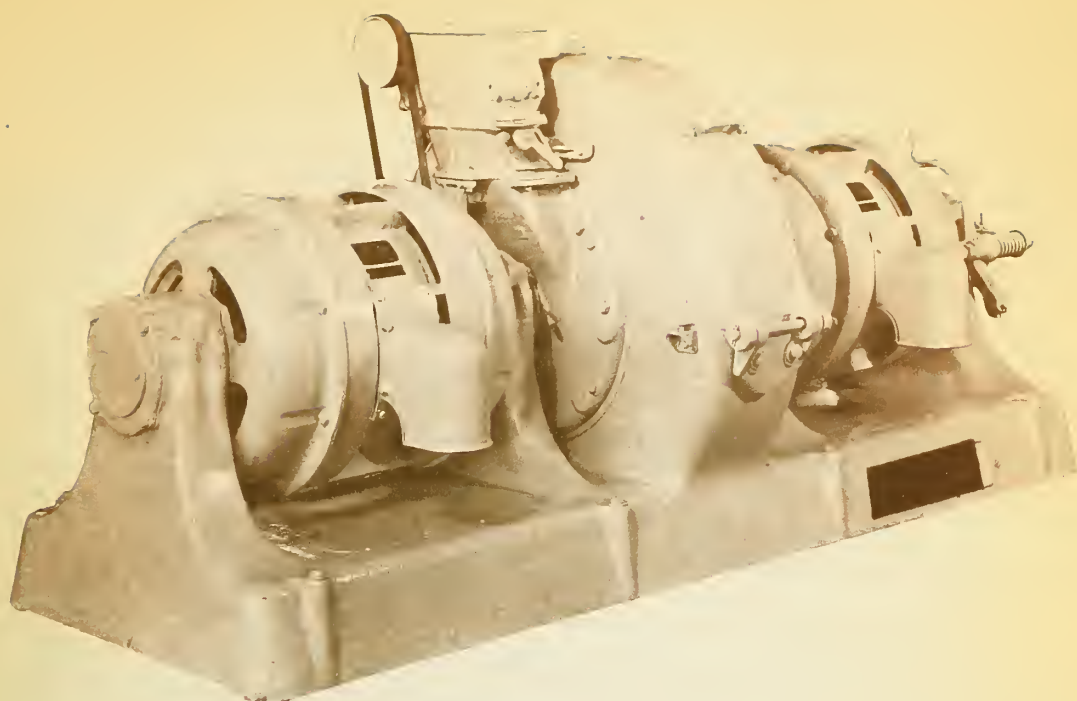


Figure 7. - A typical attrition mill, exterior view.

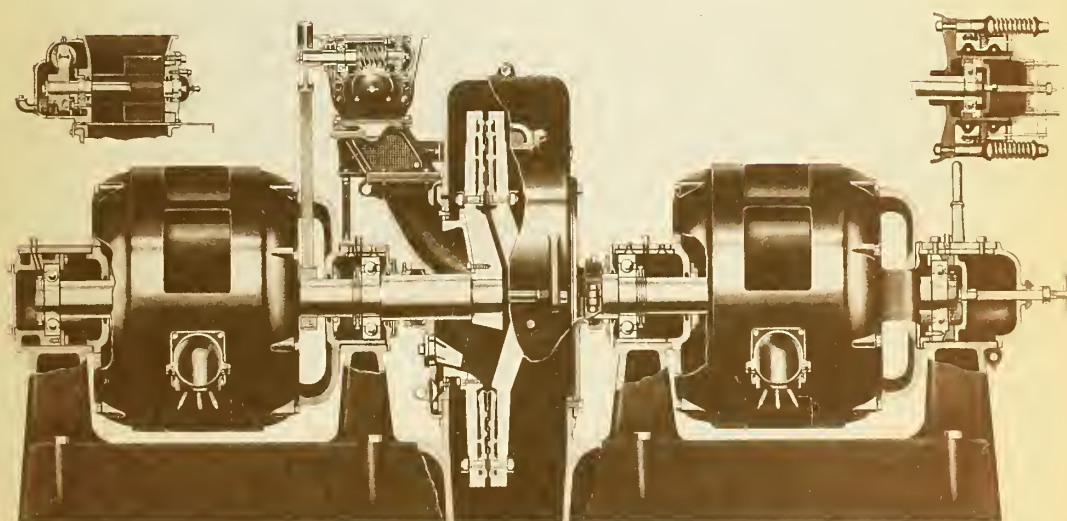


Figure 8. - A cutaway view showing the working parts of an attrition mill.

Both double- and single-disc attrition mills are used as crushers, and as intermediate and fine grinders, the use being governed largely by the type of raw material and plate patterns used. Mills fitted with spike-tooth plates, figure 10, simulate to some extent the impact action created in hammer mills. Plate patterns can be changed progressively until a relatively large proportion of grinding surface is flat, and for fine grinding may be essentially in contact. The opposite extreme, in contrast to the spike-tooth pattern, is obtained with plates prepared from fine-grained carborundum grits. Selection of plate patterns is determined largely by the nature of the feed material, the types of products desired, plate efficiency, and the grinding capacity required. Whenever possible, plates having reversible patterns should be used to prolong the service life of the plates.

Roll Crushers.--Roll crushers have already been described under the section on coarse crushers. The basic principles of design have also been applied to units for intermediate grinding. For this purpose the design, dimensions, and clearances for the tooth portion of the rotor become more critical in order that products of sufficient fineness may be obtained; which means the necessity of using machine-cut blades or teeth rather than to use "as-cast" teeth on the rotor. One unit in which 1/4-inch teeth were spaced 3/8 inch apart crushed whole cobs at a rate of 225 to 275 pounds per horsepower-hour. Only a small portion of the product was as large as 1 1/2 inches.

Rotary Knife Cutters.--Rotary knife cutters or chopping mills consist of a number of steel knives attached to a rotating arbor mounted within an enclosure of stationary knives. Cutting is done by chopping or shearing between the moving and stationary knives until the material is reduced sufficiently to pass a perforated screen below the cutting unit. Knife edges are easily dulled and damaged by metal or stones, and considerable care must be exercised to insure removal of such foreign substances from the feed materials.

One cutter having 10-inch diameter (outer edge of knives) by 18-inch long rotor, and carrying five knives was fitted with a screen of 1/8-inch diameter perforations. Crushed corncobs were chopped at the rate of 40 1/2 pounds per horsepower-hour. Essentially all of the product was finer than No. 8 and more than 90 percent classified between No. 8 and No. 30. One manufacturer estimates that his commercial size unit powered by a 50-horsepower motor has a capacity of 4,000 pounds per hour or a rate of 80 pounds per horsepower-hour. In this case practically 90 percent of the product classifies between No. 8 and No. 35 sieves, the remainder being finer material.

Buhr Mills.--Commercial processing of corncobs is being practiced with small, single-disc buhr mills, the buhrs being designed to cut or shear cob particles rather than to reduce materials by impact or attrition. The basic principle of operation of these mills is similar to that of the single-disc attrition mills except that the speed is much less for the buhr mills. Because the buhrs are available with specially machined teeth of several different sizes, these mills are used for intermediate as well as for limited fine grinding. In the latter application the major yield of ground corncobs classifies larger than No. 40. The methods required in manufacture of the buhrs limits the size of the buhrs, about 9 inches, and consequently the size of the mill. Thus, several buhr mills are required to equal the work of a 36-inch attrition mill. Use of a system of multiple buhr mills has certain advantages over

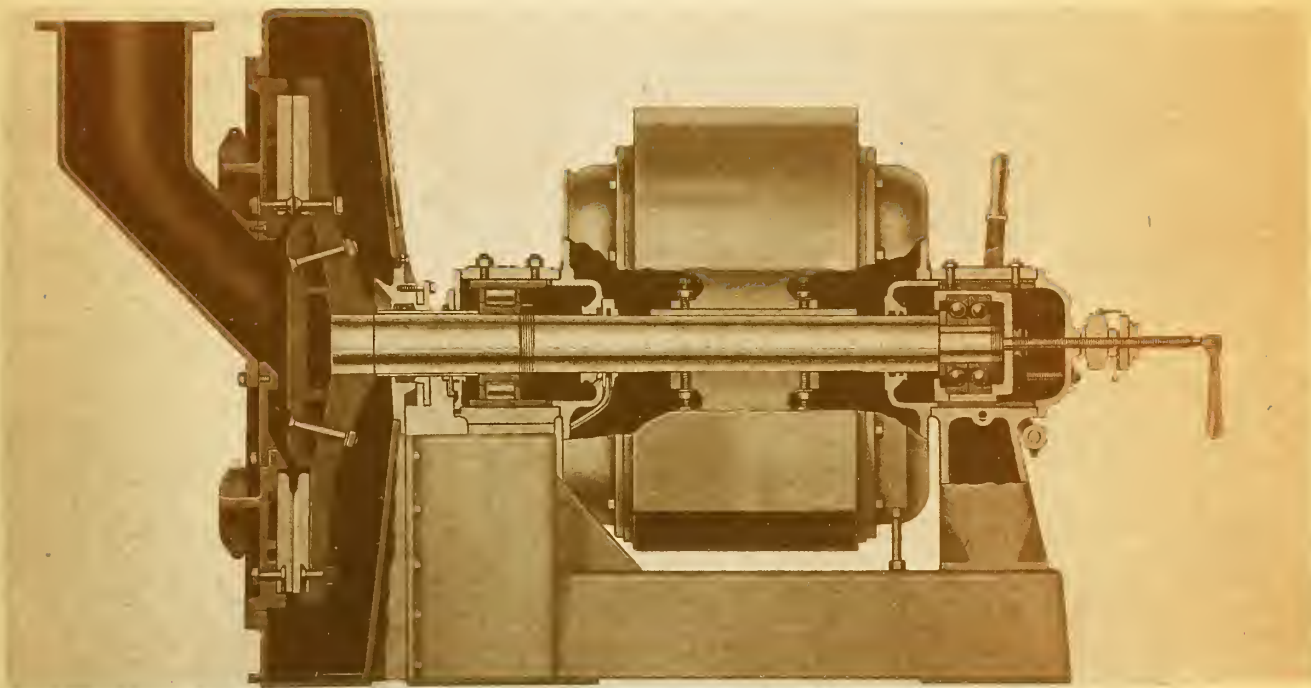


Figure 9. - A cutaway view of a single disc attrition mill. Compare with figures 7 and 8.



Figure 10. - Segments of "spike" or "devil-tooth" attrition mill plates used in crushing operations.

Table 10. - Operating characteristics of a 9-inch buhr mill fitted with buhrs of different coarseness in grinding aspirated crushed corn cob material prepared with a hammer mill having a screen with 3/8-inch diameter openings. The regrind of representative tailings is also shown

[Buhrs meshed tightly and operated at 1,300 r.p.m. unless otherwise indicated.]

Run No.	Buhr type ¹	Moisture in feed	Capacity	Power	Grinding rate	Total material passing U.S. Standard sieve indicated									
						0.25 in.	No. 4	No. 6	No. 8	No. 12	No. 25	No. 40	No. 100		
						Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	
Feed	-	-	-	-	-	96.5	59.3	19.3	5.8	1.4	0.0	-	-	-	
219 ²	1T	10.5	2,550	6.4	400	-	-	72.1	34.9	16.2	2.1	0.8	0.2	0.2	
260	1T	11.9	1,750	9.4	186	-	-	88.6	42.6	20.1	3.0	1.4	0.7	0.7	
258	1T	13.6	1,470	7.8	189	-	-	84.5	48.8	23.8	5.2	2.7	1.5	1.5	
267	2T	20.3	510	10.7	47.5	-	-	98.9	79.8	40.7	5.8	2.5	0.7	0.7	
262	2T	14.8	660	11.5	57.4	-	-	99.6	84.0	44.3	8.1	3.8	2.2	2.2	
261	2T	11.9	700	10.7	65.4	-	-	99.7	88.0	49.2	9.3	4.5	2.7	2.7	
243	2T	11.9	400	8.0	50.0	-	-	100.0	99.2	81.4	11.1	3.7	1.0	1.0	
236 ³	2T	12.4	880	12.6	70.0	-	-	99.7	82.8	43.7	8.4	3.4	0.9	0.9	
281	3T	9.8	650	12.9	50.4	-	-	-	-	52.3	15.5	7.0	2.3 ⁴	2.3 ⁴	
Grinding of tailings from previous buhr mill runs															
Feed ⁵	-	-	-	-	-	-	-	66	26	4	0.0	-	-	-	
255 ⁶	1T	10	2,290	9.7	236	-	-	98.0	70.5	28.2	3.2	1.2	0.3	0.3	
Feed	-	-	-	-	-	-	-	60.5	21.5	3.8	0.0	-	-	-	
226 ²	1T	11.9	2,370	5.9	402	-	-	89.8	51.1	18.9	3.4	1.4	0.4	0.4	
Feed ⁵	-	-	-	-	-	-	98.3	78.6	38.1	9.4	0.2	-	-	-	
264	2T	11.8	820	8.3	98.8	-	-	100.0	93.9	53.8	6.3	2.4	0.7	0.7	
247 ⁶	2T	-	950	12.1	78.5	-	-	100.0	99.7	82.4	7.8	2.7	0.6	0.6	
Feed	-	-	-	-	-	-	-	99.0	71.9	20.6	0.0	-	-	-	
266 ⁷	2T	19.1	470	8.8	53.4	-	-	99.8	90.8	49.3	5.9	2.3	0.6	0.6	
Feed	-	-	-	-	-	-	-	99.1	77.3	25.3	0.0	-	-	-	
268	3T	18.6	480	8.3	57.8	-	-	100.0	99.9	93.4	14.9	4.7	1.1	1.1	

¹ Manufacturer's designation of type. (See figure 12).

² Buhr speed 775 r.p.m.; initial clearance 0.004 inch.

³ Buhr clearance 0.004 inch.

⁴ No. 80 standard sieve.

⁵ Tailings from operations with 1T buhrs.

⁶ Tailings from operations with 2T buhrs (No. 243).

⁷ Tailings from regrind of first tailings with 2T buhrs.

the attrition mill, but these must be weighed carefully in view of certain possible disadvantages. In the multiple system, stoppage of a machine does not stop production, such as may happen with a single grinder. On the other hand, more time might be required for maintenance of several small machines than a single large machine. Mills having coarse-toothed buhrs are considered intermediate grinders because several additional operations may be necessary to reduce the materials to the desired size.

For a series of studies made with a 9-inch buhr mill, whole corn cobs were crushed in a hammer mill fitted with a screen having 3/8-inch diameter perforations. The woody fraction of the cobs used in this study was separated from the pith, beeswing, and chaff by passing it over a No. 12 screen and aspirating the larger light material from the plus-No. 12 material. The woody particles were comparable in size to those used in investigations made with a 24-inch attrition mill. The buhr mill and metering equipment is illustrated in figure 11. A variety of machine-cut buhr patterns used in intermediate and fine grinding is shown in figure 12. Teeth of the buhrs are pyramidal. The dimensions at the base for the coarsest buhr are: face 0.60 inch, length 0.75 inch, and height 0.45 inch. Size of the teeth for finer buhrs decrease to a minimum of 0.100-inch face and 0.150-inch length.

With a loose setting (0.004 inch) for coarse buhrs and a speed of 775 r.p.m. maximum grinding efficiency--about 400 pounds per horsepower-hour overall or 65 pounds per horsepower-hour for minus-No. 12 material--was obtained with a feed rate of 2,550 pounds per hour. Slightly better results, 76 pounds per horsepower-hour for minus-No. 12 material, were obtained when the plus-No. 12 tailings from the initial run were reground at a rate of 2,370 pounds per hour, other conditions remaining the same. When the coarse buhrs meshed tightly and were operated at 1,300 r.p.m. the grinding rates decreased and the efficiency was lowered. Tests were continued with buhrs having finer teeth. Most striking of the results is the low yield of fines or material finer than No. 25. Results of this phase of the study are reported in table 10. The products obtained when cutting was done with the coarsest buhr were more bulky and one dimension of the particles tended to be longer than the others; with medium buhrs the dimensions tended to be much the same in all directions.

Production rates attained with the buhr mills are considerably higher than those attained with attrition mills. It must be realized that this comparison is based on products finer than No. 12 and that considerable differences exist in the amount of fines (minus-No. 100) as well as in the character of the products from the two types of mills. As the name implies, the attrition mill reduces by attrition as well as by cutting and shearing. This action is influenced by the plate patterns used in the attrition mills. The attrition action favors production of compacted cob grits for soft-grit blast operations while the cutting or shearing action of the buhr mill favors production of materials of higher absorbency for use in the electroplating industry. A greater proportion of fines in the product is obtained with the attrition mill than with the buhr mill. In shape and other physical characteristics the cob products from buhr mills are about midway between those from roller mill and those from attrition mills.

Table 11.- Operating characteristics and character of product when grinding flax shives and rice hulls in a 24 x 30-inch ball mill

Period of grinding	Power consumption, cumulative	Total material passing U.S. Standard sieves indicated											
		No. 4	No. 12	No. 20	No. 35	No. 50	No. 60	No. 80	No. 100	No. 140	No. 200		
Hours	Kw.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent		
Flax shives													
0	1.04	73.8	32.6	12.1	2.9	1.1	-	-	-	-	-	-	-
1	1.00	86.0	76.1	39.9	15.9	6.9	-	-	2.8	-	-	-	-
2	2.06	96.5	85.1	48.2	21.2	9.8	7.1	4.6	2.5	-	-	-	-
4	6.60	-	90.5	60.6	32.2	15.9	11.0	7.3	4.6	-	-	-	-
8	15.84	-	96.1	88.6	71.4	46.1	36.3	26.9	19.1	-	-	-	2.1
10	20.68	-	-	96.7	90.2	78.2	68.0	55.0	43.4	-	-	-	11.9
16	34.6	-	-	99.0	96.5	92.0	89.3	87.1	81.3	-	-	-	29.0
													65.7
Rice hulls													
0	1.04	-	-	-	3.7	-	1.6	1.2	0.9	-	-	-	-
1	1.03	-	-	-	38.9	-	17.4	10.2	6.4	4.1	-	-	-
2	2.12	-	-	-	81.0	-	53.2	40.6	32.0	25.9	15.8	-	-
4	4.40	-	-	-	99.2	-	80.5	65.0	49.8	38.5	28.1	-	-
8	9.00	-	-	-	-	-	97.7	90.6	78.1	63.2	47.7	-	-
10	11.22	-	-	-	-	-	97.7	93.8	85.2	73.0	57.5	-	-
16 ¹	18.06	-	-	-	98.9	-	95.8	93.1	88.9	81.6	69.5	-	-

¹ The apparent decrease in yields at this period was caused by formation of flakes and pellets of the more finely ground materials.

Mill charge: 300 pounds of assorted porox balls and 30 pounds of the agricultural residue. Mill speed: 37.8 r.p.m. Power demand at zero hours is power required to operate the mill containing only the porox balls.



Figure 11. - Pilot-plant assembly of buhr mill for experimental purposes. Note typical buhr, orifice plate, potentiometer, and recording wattmeter.

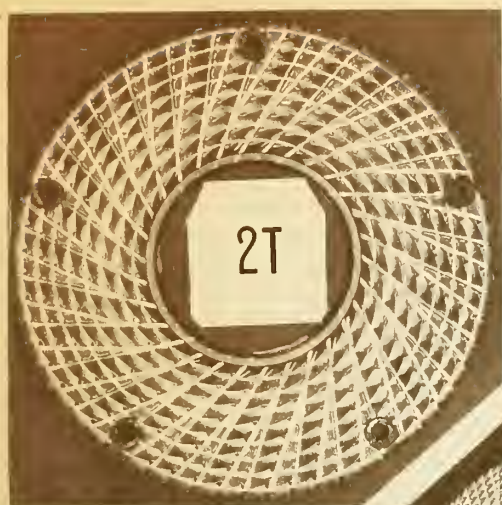
FINE GRINDING

Ball Mills.--The ball mill, as the name implies, grinds through the action of steel or special ceramic balls rolling or tumbling over one another within a rotating cylinder. Rod mills in which metallic rods replace the balls may be considered in this same category. The grinding action is a combination of impact and attrition, the latter being the more pronounced. Although the action is slow, extremely fine products may be obtained if sufficient time is allowed for grinding. Grinding by means of a ball mill is generally a batch operation with sufficient time being allowed for reduction of all materials to a predetermined maximum size. This practice makes it possible to grind materials of mixed physical and chemical properties and to retain these properties in their proper proportions in the product. Where removal of fines as produced is desired, a stream of air through the mill picks up the fines which are subsequently recovered in a cyclone collector or other dust-collecting unit. Addition of fresh feed in an amount equal to the fines removed makes this method a continuous operation.

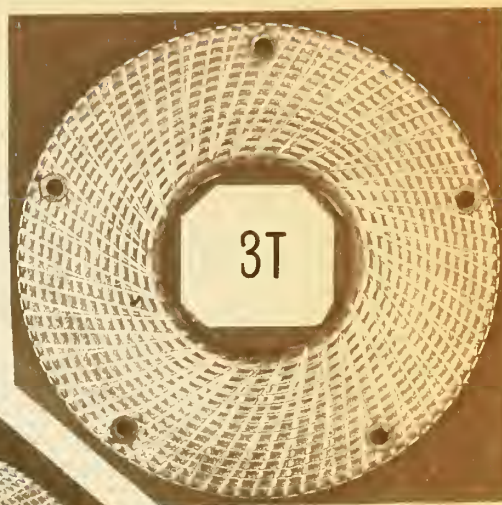
To illustrate some of the characteristics of ball mills for grinding agricultural residues the results of two grinding experiments are stated: A ceramic-lined ball mill 24 inches in diameter and 30 inches long (inside dimensions) with 100 pounds each of porox balls 1½, 2, and 2½ inches in diameter and a charge of 30 pounds of flax shives, or of rice hulls was operated at 37.8 r.p.m. Progress of grinding was followed by sieve analyses each hour; power consumption was determined throughout the runs by means of a recording wattmeter. Data on the grinding of flax shives and rice hulls are presented in table 11. The inherently dense fibrous character of flax shives accounts for the slower rate of grinding and the greater power consumption in contrast to the requirements for rice hulls. It should be noted that the power required in grinding the rice hulls was only slightly more than that required to operate the mill without hulls. In the case of rice hulls the most effective reduction occurred during the first 2 hours of grinding, whereas with flax shives 8 to 9 hours of operation was required to obtain comparable yields. Under such conditions the yields of ground products in terms of pounds per horsepower-hour are too low to be considered other than for academic purposes.

The ball mill is, therefore, not well suited to the processing of agricultural residues except in limited quantities for experimental purposes. Even then, the physical character of the products is not comparable to that of products available from commercial operations. The bulky nature of many agricultural residues and the slow action of the ball mill make this method of processing expensive.

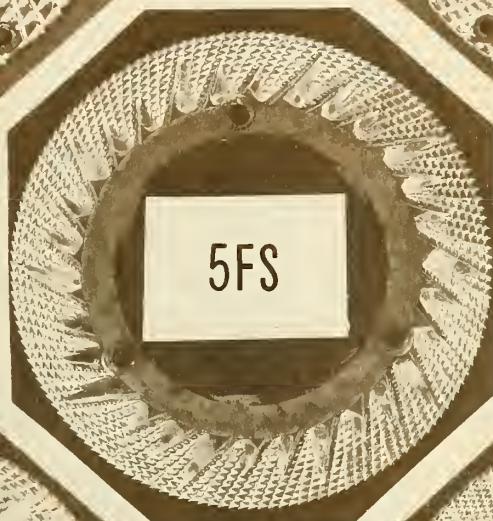
Roller Mills .--Pairs of horizontal steel rolls turning toward each other at different speeds comprise the working units of the roller mill. Material is ground between the rolls by combinations of compression and shear. It has been reported (31) that the roller mill was first used in 1449 by Pietro Speciale in Sicily for crushing sugarcane. At that time vertical wooden rolls were used. It was almost 300 years later before horizontal iron-cored rolls came into use for the milling of flour. The present-day steel rolls carry spiral corrugations or grooves on their surface, the number, shape, size of grooves and pitch being dependent upon the degree of reduction and particle characteristics desired in the product. The pitch of the corrugations



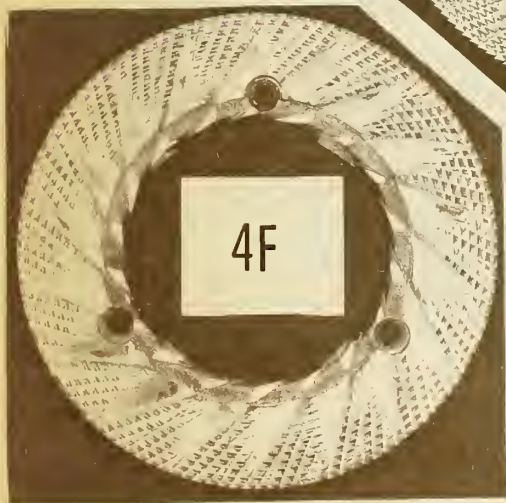
2T



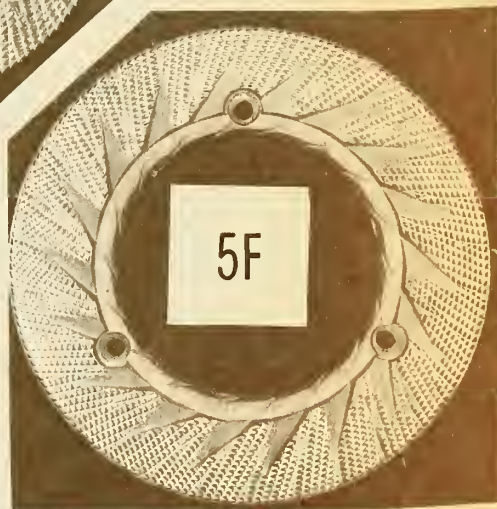
3T



5FS



4F



5F

Figure 12. - Typical buhr patterns used in intermediate and fine grinding.

Table 12.- *Results obtained in grinding crushed corncobs in roller mills
with corrugations running sharp to sharp*

Item	:	1	:	2	:	3	:	4	:	5	:	6
Moisture, percent	:	4.5	:	4.5	:	7.5	:	Dry	:	7.5	:	Dry
Motor size, hp.	:	5	:	5	:	2	:	2	:	2	:	2
Roll clearance, inch	:	0.003	:	0.003	:	0.001	:	0.001	:	0.001	:	0.001
Roll size, inch	:	9 x 11-3/4	:	9 x 11-3/4	:	6 x 6	:	6 x 6	:	6 x 6	:	6 x 6
Corrugations:	:		:		:		:		:		:	
Slow, no./inch	:	6	:	12	:	12	:	12	:	12	:	12
Fast, no./inch	:	6	:	6	:	12	:	12	:	12	:	12
Spiral	:	1°	:	1°	:	1 revolution in 20 feet of length	:		:		:	
Speed:	:		:		:		:		:		:	
Slow roll, r.p.m.	:	625	:	625	:	450	:	450	:	291	:	291
Fast roll, r.p.m.	:	1,310	:	1,310	:	630	:	630	:	630	:	630
Total percentage of material passing sieves indicated												
No. 4 sieve	:	100.0	:	100.0	:	-	:	-	:	-	:	-
No. 8 sieve	:	95.5	:	92.5	:	74.5	:	95.5	:	94.5	:	99.0
No. 10 sieve	:	82.0	:	77.0	:	44.0	:	76.5	:	85.0	:	96.5
No. 12 sieve	:	-	:	-	:	40.0	:	73.5	:	82.5	:	96.0
No. 20 sieve	:	27.0	:	26.0	:	8.0	:	20.0	:	36.0	:	61.0
No. 35 sieve	:	10.5	:	10.5	:	-	:	-	:	-	:	-
No. 50 sieve	:	4.5	:	4.5	:	-	:	-	:	-	:	-
No. 60 sieve	:	3.0	:	3.5	:	-	:	-	:	-	:	-
No. 80 sieve	:	2.0	:	2.0	:	-	:	-	:	-	:	-

together with the differential speed of the rolls results in a shearing action, the compressive action being limited by the design and clearance of the rolls. Reduction of materials is stepwise so that a number of pairs of rolls must be used in grinding materials to predetermined sizes. Frequently several pairs of rolls will be incorporated into a single stand or unit. Several factors such as roll speed; the number, size, shape, and angle of corrugations; and roll clearance must be given careful consideration in grinding agricultural residues. The usual practice is to employ several single or double stands of rolls. After passing the material through a stand of rolls the material is screened. The oversize materials or tailings are either passed to roll stands of closer clearance or re-cycled until a product of the desired size is obtained. As with most equipment, roller mills may be operated above their capacities, but this practice is not recommended because of the increase in maintenance costs. A view of a modern roller mill is shown in figure 13.

Roller mill manufacturers claim production rates of 1 ton to more than 1 1/4 tons per hour of ground corncobs for four stands of 9-inch by 30-inch rolls when 15 horsepower motors are used on each roll stand. The influence of corrugations, roll speed, and moisture on the particle size of ground corncobs is indicated from the data presented in table 12.

Bowl Mills or Pulverizers.--A pulverized product can be produced by machines in which the grinding action is effected by the movement of steel balls or rollers within a circular raceway or bowl. The rapid rotation of the balls or rollers results in large centrifugal forces that are expressed as the compression and attrition action between the balls and the raceway. In all bowl mills the motivating forces are transmitted by a vertical shaft located on the central axis with respect to the bowl. Where rollers are used they are usually attached to the lower end of swinging arms pivoted from the ends of a spider on the central shaft. Where balls are used the design may be simplified, only a paddle arrangement being necessary to push the balls about the bowl.

These mills are usually operated under such conditions that particles smaller than a certain predetermined size are air-swept from the mill and subsequently classified to the finer desired sizes, the coarser materials being constantly returned to the mill. Equipment of this type is usually provided with a built-in air classifier so that only products of the desired fineness are removed from the mill. These features might limit the possible application in processing agricultural residues because the entire product would classify as a flour whereas, in most instances in processing residues, it is more desirable and economical to produce a variety of merchandisable sizes.

Data were accumulated in fine grinding flax shives and wheat straw with a pilot-plant model of a roller pulverizer. These data are shown in table 13. In both cases the feed materials had been pre-ground in a hammer mill fitted with a screen having 1/2-inch diameter perforations in order to provide steady flow of material to the bowl mill. The manufacturer claimed that with a 60-horsepower motor on the mill and a 20-horsepower motor on the classifier the capacity of a commercial unit would be 100 times that of the pilot unit.

Attrition Mill.--The attrition mill has been described and discussed briefly under the section on intermediate grinders. In processing agricultural residues the attrition mill in most instances functions as a fine grinder.

Corncob material for pilot-plant studies with a 24-inch, 100-horsepower attrition mill was prepared by crushing whole corncocks in a hammer mill fitted with a screen having perforations of such size, usually 3/8-inch diameter, that essentially all of the husks, beeswing, chaff, and pith were loosened from the cob particles. The woody portion was recovered by separation over a No. 12 screen and aspirated to remove the coarser light fractions. This cleaned, crushed, plus-No. 12, cob material was carefully blended, the moisture content adjusted, and moisture content checked at the time of grinding in the attrition mill. Feed rates for material were determined from the times required to grind known weights of feed materials. Uniformity of feeding was attained through use of a belt type volumetric feeder. Results of several series of grinding runs made with both cleaned, crushed cob material and plus-No. 12 tailings from previous attrition mill runs are reported in table 14. These data were obtained using only one plate pattern which has proved effective in processing corncocks. "Soft grits, blasting" referred to in the table are ground corncob materials classified as No. 12/30 by sifting on a double deck vibrating screen and subsequent aspirating to remove low-density components. The bulk density of the soft grits so produced was approximately 34 pounds per cubic foot.

It will be noted in the table that the feed rates are presented on a basis of wet cob material, whereas grinding rates in pounds per horsepower-hour are presented on a dry basis. This permits one to observe the effects of moisture content on capacity and grinding rate, as well as to compare grinding rates on the basis of non-volatile solids--the materials in which the plant operator is vitally concerned.

In grinding crushed corncocks in a 24-inch double-disc attrition mill very little difference in yields of ground products was observed when the crushed cocks had moisture contents ranging from 10 to 17 percent. Results were sufficiently close so that the yields could be represented as averages of the several determinations. When the moisture content of the crushed cocks was approximately 5 percent, an appreciable increase in yield of products of finer particle size was noted. These observations were made when the plate clearance was 0.040 and 0.050 inch. The results are presented graphically in figure 14. The increase in yields when the moisture content was lowered to 5 percent is attributed to a brittleness in essentially dry cob material, whereas the cob material of higher moisture content is quite tough and resilient.

While the major portion of these investigations was made with a 24-inch attrition mill, some time was also devoted to investigations with a 36-inch attrition mill, a size frequently used in commercial processing operations. It is significant that with the larger mill operating at the same grinding rate (basis dry feed) as the smaller mill, the yields of fine products were greater with the larger mill. The explanation is that with the larger mill, the materials are subject to a greater amount of shear and abrasion. The increase in yields is not necessarily proportional to plate diameters or grinding areas of plates, because other factors, such as speed of rotation or peripheral speed, are involved. Establishment of yield relationships among mills of various sizes would make possible the prediction of the proper size, within reasonable limits, from tests on a mill of a different size. Such a relationship can be

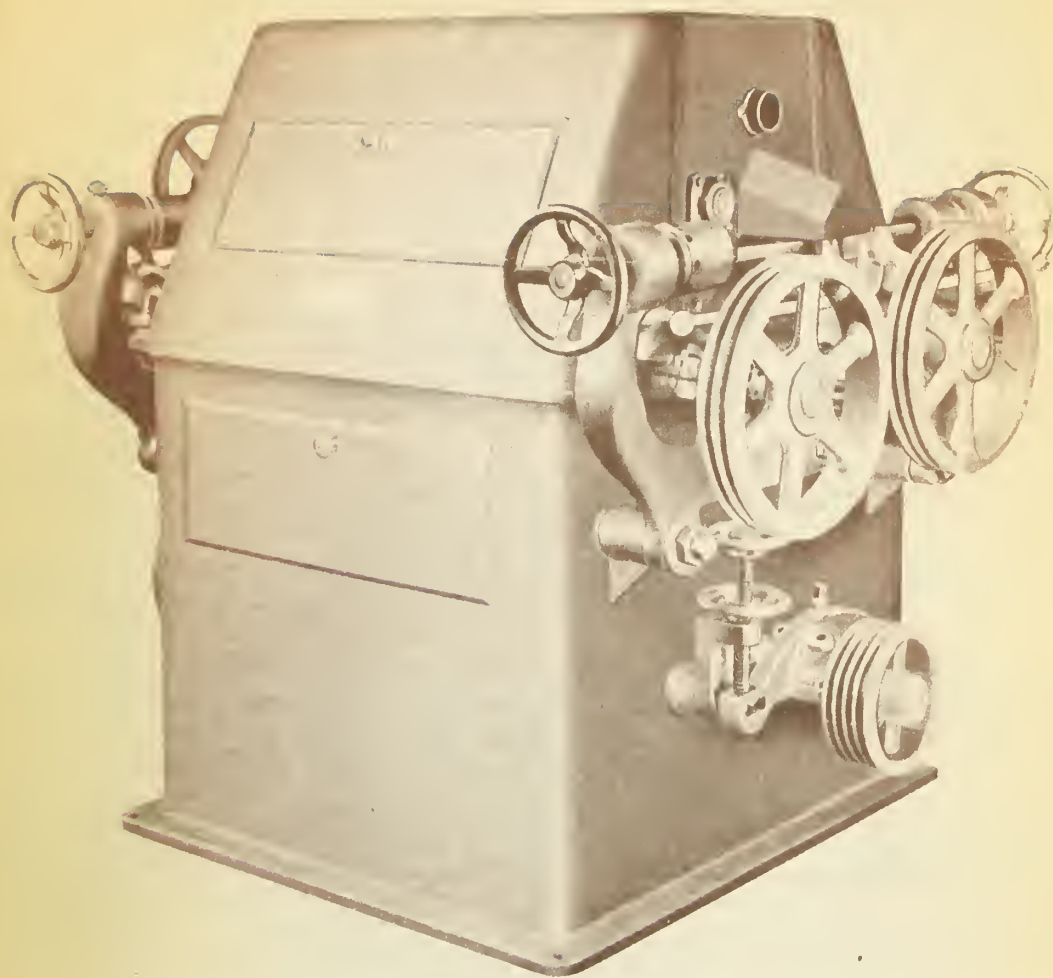


Figure 13. - A typical modern roller mill.

Table 13.- *Capacity and particle size of flours prepared by grinding flax shives and wheat straw in a pilot-size roller mill pulverizer provided with an air separator*

Material	Capacity	Total material passing sieves indicated			
		No. 40	No. 60	No. 80	No. 100
	<i>Lb./hr.</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>	<i>Percent</i>
Flax shives	4.5	100	99.4	97	90
Wheat straw	4	100	99.5	95	80

Pulverizer powered by 7 1/2 hp. motor.

approximated for attrition mills of 24- and 36-inch diameter from curves of yields presented in figure 15. The curves are based on results obtained when the moisture content of the crushed corncobs was 13 percent (24-inch) and 18 percent (36-inch). Although the plate clearance (0.060 inch) for the 36-inch mill was 0.010 inch greater than for the 24-inch mill (0.050 inch), the greater yield for the larger mill is very striking. The yield relationships can be approximated simply by measuring the vertical distance on each curve to the point indicating the size of product desired and calculating the relationship. The application of the percentage values instead of actual measurements simplifies the calculation. Thus, the values of 44.7 and 26.9 percent for minus-No. 25 material shows a relationship of 44.7:26.9 or 1.66:1. This means, that the yield of minus-No. 25 material from the 36-inch mill is approximately 66 percent, or two-thirds greater than that from the 24-inch mill. Values for other sizes can be determined in a similar manner.

A relationship between plate clearance and grinding rate (dry basis) for the 24-inch mill is shown in figure 16 when crushed cobs were fed at a constant rate of approximately 1,400 pounds per hour and the moisture content of the crushed cobs was 13.1 percent. Power required under those conditions ranged from 78 to 124 percent of the motor capacity for clearances between 0.070 and 0.040 inch, respectively. This can be expressed as:

$$C = 5.715R + 17.14$$

where C is plate clearance in inches and R is the grinding rate (dry basis) in pounds per horsepower-hour.

Results obtained in processing a variety of agricultural residues in double-disc attrition mills under various conditions are presented in table 15. These data should not be considered as a guaranteed performance rating, but they are indicative of the results which have been actually observed. Data pertaining to a few wood wastes are included for comparative purposes. Several plate patterns, including the fine-tooth flat and the grid, are illustrated in figure 17. Many variations of these patterns are available, but the most satisfactory for use can be determined only after thorough testing.

Disc Mills--Small disc mills, modifications of attrition mills, provide means for studying comparative power requirements, grinding rates, and similar factors on a small scale and may be used as production units for certain materials. One such mill, having 8-inch diameter discs and an integral 5-horsepower motor, and operated at 3,600 r.p.m., was used experimentally for grinding several shell residues. The mill hopper was provided with interchangeable orifices so that constant feed by gravity could be maintained. The size of feed available was influenced to a large extent by the size of the residues resulting from original processing operations such as cracking and shelling. Where necessary, the feed material was classified prior to grinding so that all of it was essentially the same size. Furthermore, the plate clearance was maintained at a constant value during these studies so that grinding rates might serve as a quantitative measure of the relative ease of grinding. Grinding rates increase with ease of grinding. Results of this study are presented in table 16, and are in the order expected as judged by the physical appearance of the shells.

Table 14. Power requirements, grinding rates, and yields when grinding aspirated crushed corncob material in a 24-inch double-disc attrition mill fitted with medium grid-type plates¹

Run No.	Inch	Moisture content	Feed rate (capacity)	Power used	Grinding rate	Total material passing U.S. Standard sieves indicated										Yield of soft grits, blasting	
						Basis: air-dry					basis: feed					No. 100	
						lb./hr.	hp.	lb./hp.-hr.	Percent	Percent	Percent	Percent	Percent	Percent	Percent		
		Percent	lb./hr.	hp.	lb./hp.-hr.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent		
200	.040	17.3	950	90.6	10.5	98.8	84.1	58.5	17.9	8.2	3.9	2.4	26.5				
208	.070	13.1	1,420	78.3	18.1	87.2	56.4	34.9	13.5	7.7	4.5	3.0	7.7				
207	.060	13.1	1,320	87.7	15.1	94.6	72.7	53.4	28.2	17.3	10.1	6.6	7.4				
206	.050	13.1	1,400	102	13.8	12.0	78.7	56.3	28.4	17.7	10.7	6.9	10.6				
205/9	.040	13.1	1,400	117	12.0	10.5	76.7	55.2	22.2	14.4	7.8	5.3	12.2				
181	.050	5.5	1,710	99	17.3	16.4	97.9	76.1	35.2	23.1	15.1	9.6	23.1				
179/0	.050	5.5	1,425	82.1	17.4	16.4	96.4	74.9	37.8	20.6	12.2	8.5	23.1				
176	.050	5.5	1,340	84.5	15.9	15.0	97.2	77.4	38.8	20.9	13.0	8.0	24.8				
178	.050	5.5	1,280	74.7	17.1	16.2	97.0	72.9	38.0	19.5	12.2	7.9	22.3				
177	.040	5.3	1,350	97.5	13.9	13.2	98.5	82.1	41.3	22.7	14.0	8.8	26.5				
20X-1 ²	.060	—	2,640	164	16.1	—	—	89.9	38.7 ³	28.2	18.8	12.2	—				
20X-2	.060	4	2,400	155	15.5	—	—	80.5	27.7 ³	18.8	12.5	7.7	—				
Tails, No. 4/12 (passing through No. 4 sieve and retained on No. 12)																	
204/3	.040	7.7	2,140	101	21.2	20.0	97.8	73.7	25.0	18.0	11.7	7.4	31.6				
202	.040	7.7	1,640	79.8	20.5	18.9	97.1	68.4	14.1	9.2	5.6	3.6	32.3				
201	.030	7.7	1,850	92.2	20.1	18.5	98.3	76.3	21.0	—	9.4	6.1	33.2				

¹ Aspirated cob material was classified between 3/8 inch and No. 12. Feed material distribution, total passing standard sieves: 1/4 inch, 96.5 percent; No. 4, 59.3 percent; No. 6, 19.3 percent; No. 8, 5.8 percent; No. 12, 1.4 percent.

² CX indicates runs made with a 36-inch attrition mill.

³ No. 30 U.S. Standard sieve.

⁴ Feed classified between 1/2 inch and No. 12.

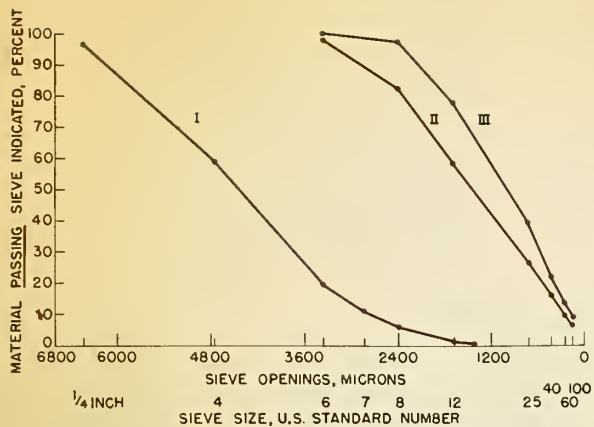


Figure 14. - Particle distribution in ground products prepared by grinding aspirated crushed corncob material in a 24-inch double disc attrition mill with the plate clearance ranging from 0.040 to 0.050 inch.

Curve I: Original material.
 Curve II: Moisture content of feed materials ranged from 10 to 17 percent.
 Curve III: Moisture content of feed materials, 5 percent.

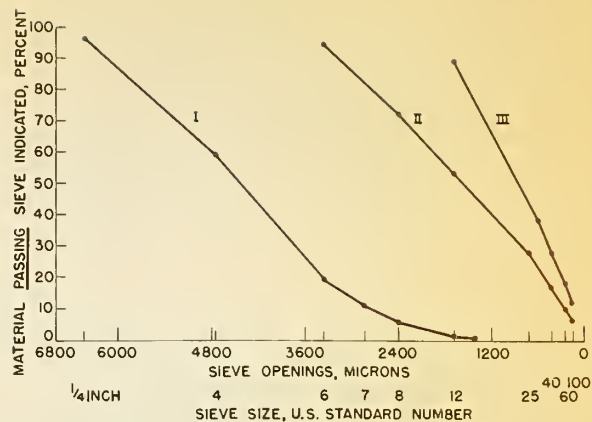


Figure 15. - Comparison of particle distribution in the ground products from 24- and 36-inch double disc attrition mills with distribution in the original crushed corncob material.

Curve I: Original material.
 Curve II: Product from 24-inch mill with 0.050 inch plate clearance.
 Curve III: Product from 36-inch mill with 0.060 inch plate clearance.

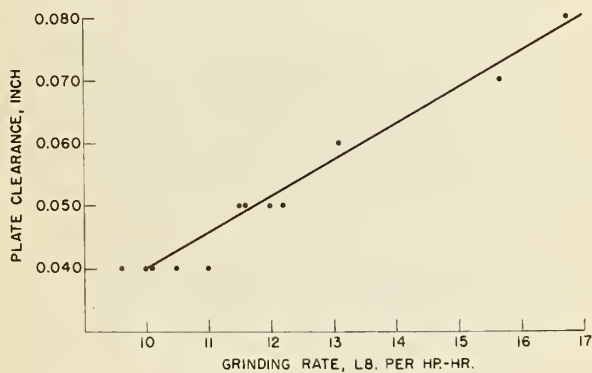


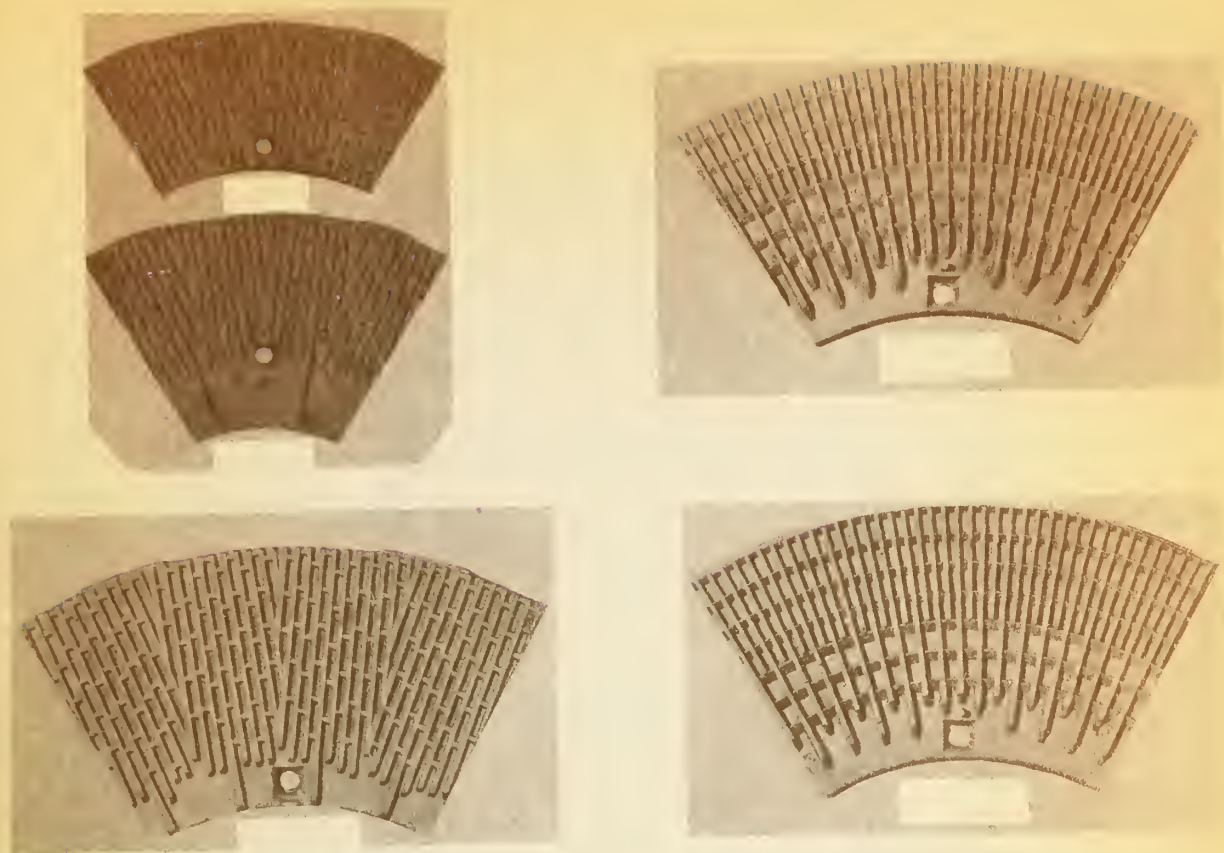
Figure 16. - Relationship between plate clearance (inch) and grinding rate (pounds per horsepower-hour) when cob material was ground in a 24-inch attrition mill at a feed rate of 1400 pounds per hour.

Table 15. - Grinding characteristics of 36-inch double-disc attrition mills in grinding several types of agricultural residues

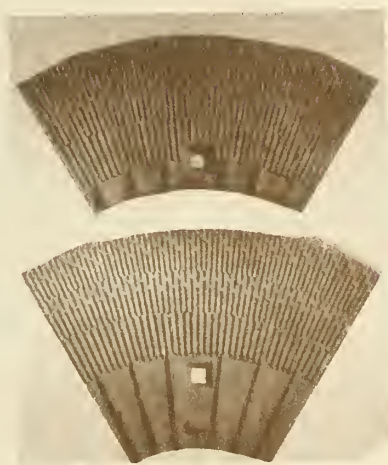
Type of residue	Moisture : Screen : Type :			Plate :			Feed : Power : Grinding rate :			Total material passing		
	content :	openings :	of :	clearance :	rate :	used :	air-dry basis :	sieves indicated				
	of feed :	plate :							No. 80	No. 100	No. 200	
	Percent	Inch	Inch	Lb./hr.	Hp.	Lb./hp.-hr.	Percent	Percent	Percent	Percent	Percent	Percent
Almond shells	-	-	T	Nipping	775	142	5.5	97.0	94.5	83.5		
Apricot pit shells	-	1/4	T	.0125	1,350	-	-	-	87.9	81.5		
Black walnut shells	16.6	1/4	G	.002	3,860	146	26.4	-	53.0	35.8		
	-	1/4	G	Nipping	1,310*	64	20.7	-	40.8	26.1		
Coconut shells	15.0	3/4	G	.005	2,520	110	22.9	54.0	42.4	18.7		
	15.0	1/4	G	.015	2,770	120	23.1	-	61.8	52.6		
Corn cobs	18.4	3/8	G	.060	2,640	164	16.1	-	12.2	-		
	15.4	5/16	G	.025	2,710	150	18.0	17.7	-	-		
	15.4	1/2	G	.010	2,550	160	16.0	18.3	-	-		
	10.8	1/4	G	.003	1,880	149	12.6	30.3	-	-		
	18.4	5/16	G	.060	3,000	166	18.0	-	8.8	-		
Corn stover	-	1/8	T	Nipping	1,700	156	10.9	72.3	65.3	-		
English walnut shells	-	3/4	G	Nipping	4,600	150	31.7	46.9	39.5	24.6		
Flax shives	-	-	T	Nipping	1,160	134	8.7	82.0	75.3	-		
Hemp hurds	-	1/8	T	Nipping	2,280	148	15.4	74.2	68.6	-		
Peach pit shells	-	1/4	G	.025	2,500	160	15.6	72.1 ¹	-	49.2		
Peanut shells	-	-	G	.012	4,340	135	32.1	50.9	41.6	17.4		
Pecan shells	20.0	3/8	G	.003	3,560	152	23.4	50.4	44.5	31.9		
	-	-	G	.050	6,040	166	36.4	41.1	35.4	24.6		
	-	-	G	.025	3,940	145	27.2	54.6	44.4	20.6		
	20.0	3/8	G	.010	4,000	150	26.7	44.1	38.6	27.9		
	-	1/4	G	Nipping	3,910	139	28.1	48.5	41.2	38.0		
	-	-	G	Nipping	3,220*	56	57.8	35.7	31.5	22.2		
Rice hulls	10.0	-	G	.025	5,930	150	39.4	41.8	31.0	21.1		
	10.0	-	G	.010	4,500	150	30.0	51.8	39.2	26.6		
	10.0	-	G	.003	3,720	139	26.8	54.8	40.4	26.0		
	-	-	T	Nipping	1,700	148	11.5	74.6	60.0	38.0		
Soybean hulls	-	-	G	Nipping	3,220	30	107	-	11.0	-		
Wheat straw	-	1/8	T	Nipping	1,160	134	8.7	68.8	59.0	-		
Douglas fir shavings	20.0	1/4	G	.001	2,080	142	14.6	30.0	25.3	-		
Pine shavings	8.5	-	G	Nipping	2,310	147	15.6	25.4	-	-		

¹ Minus No. 70 material

Asterisks indicate a 24-inch attrition mill. Plate patterns are: G, grid; and T, fine tooth flat. Size of openings in hammer mill screens indicate preparatory treatment of the residues. Data supplied by cooperating equipment manufacturers



Plates 1-5, grid-types, reversible.



Plates 6-7, fine-tooth flat, non-reversible.

Figure 17. - Segments of attrition mill plates for fine grinding.

Table 16. - Conditions, power requirements, and product characteristics when several agricultural residues were ground in a single-runner disc mill

Residue	Moisture content	: Feed : : size : ing, : : U.S. : diam- : Pro- : std. : eter : : duct :	: Feed : : rate : : U.S. : diam- : Pro- : std. : eter : : duct :	: Power : : used : : rate : : U.S. : diam- : Pro- : std. : eter : : duct :	Grinding rate	Total material passing U.S. Standard sieves indicated															
						4	6	7	8	10	12	16	20	30	50	70	100	140	200		
Percent																					
Percent	No.	Inch	Lb./hr.	Hp.	Lb./hp.-hr.	Percent															
Apricot pit	10.0	7.6	4/12	25/32	128	2.65	48.5	-	-	100.0	1	99.9	98.6	65.7	30.9	20.0	10.9	8.1	5.9	4.2	3.1
Black walnut	9.3	9.2	4/12	25/32	144	3.00	48.1	-	100.0	1	99.8	-	95.9	60.2	35.1	23.8	13.7	10.7	7.8	5.5	4.2
Peach pit	9.7	7.7	4/12	25/32	172	3.33	51.8	-	-	-	100.0	-	99.3	69.6	38.8	26.0	14.5	10.9	7.9	5.6	4.2
English walnut	9.8	9.0	4/12	25/32	144	2.48	58.3	100.0	1	99.9	99.6	98.8	93.0	54.6	24.6	15.8	10.2	8.1	6.2	4.5	3.4
Filbert	11.0	9.1	4/12	13/16	219	2.84	76.9	-	100.0	1	99.8	99.1	93.9	54.4	20.5	15.1	11.5	9.1	7.0	5.3	4.2
Pecan	14.1	13.3	5/12	47/64	308	2.75	114	-	100.0	99.9	99.0	-	74.9	32.4	16.3	12.2	8.7	7.1	-	-	-

¹ Traces of material larger than the sieve indicated were observed.

Plate size: 8-inch diameter; clearance, 0.035 inch; plate pattern, grid type.

Table 17.-*Characteristics of a 9-inch buhr mill fitted with buhrs of different coarseness in fine grinding tailings from previous grinding of aspirated crushed corn cob material in the buhr mill*

[Particle distribution of feed material and product is shown. Buhrs meshed tightly and operated at 1,300 r.p.m.]

Run No.	Buhr type	Moisture in feed	Capacity	Power	Grinding rate	Total material passing U.S. Standard sieve indicated									
	No.					No. 6	No. 8	No. 12	No. 16	No. 25	No. 40	No. 80			
		Percent	Lb./hr.	Hp.	Lb./hp.-hr.	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
Feed	-	-	-	-	-	99.0	71.9	20.6	0.0	0.0	-	-	-	-	-
265	2T	10.0	1,520	8.3	184	100.0	93.2	45.4	-	4.3	1.7	0.4	-	-	-
Feed	-	-	-	-	-	99.1	77.3	25.3	0.0	0.0	-	-	-	-	-
268	3T	18.6	480	8.3	57.8	100.0	99.9	93.4	-	14.9	4.7	1.1	-	-	-
Feed	-	-	-	-	-	100.0	95.3	53.8	4.1	0.7 ¹	-	-	-	-	-
274	4F	13.3	440	10.5	41.9	-	100.0	99.1	67.1	16.3	4.5	1.4	-	-	-
273	5F	13.3	320	11.3	28.3	-	-	97.4	56.3	15.1	6.1	2.5	-	-	-
272	5F	13.3	190	10.2	18.6	-	-	99.1	91.0	37.2	12.5	4.1	-	-	-
277	5FS	11.8	390	11.3	34.5	-	-	99.9	86.8	34.7	10.9	3.3	-	-	-
280	5FS	13.3	770	14.2	54.3	-	-	98.9	55.9	17.3	6.3	2.1	-	-	-
Feed	-	-	-	-	-	-	-	100.0	64.9	3.2 ¹	0.0	-	-	-	-
270	5F	13.8	400	11.5	34.8	-	-	100.0	95.6	33.1	11.8	4.0	-	-	-
271	5F	13.8	310	10.7	29.0	-	-	100.0	94.2	29.7	7.7	2.5	-	-	-
276	5FS	16.6	410	8.0	51.2	-	-	100.0	93.0	32.2	8.5	2.1	-	-	-
278	5FS	11.4	550	9.5	57.9	-	-	100.0	94.2	28.4	6.8	2.3	-	-	-
Feed	-	-	-	-	-	19.3	5.8	1.4	0.0	-	-	-	-	-	-
282A ²	2T	9.9	740	11.7	63.5	-	-	42.6	19.1	6.5	2.7	0.7	-	-	-
282B	3T	9.2	630	13.2	47.7	-	-	93.2	58.8	25.1	11.7	4.0	-	-	-
282C	5FS	7.9	650	10.2	64	-	-	100.0	93.1	45.4	16.9	5.5	-	-	-

¹ No. 20 sieve.

² A series of runs made in sequence without intervening sifting of the products. The original feed also contained cob particles, 96.5 percent passing a 0.25-inch sieve and 59.3 percent passing a No. 4 sieve.

Buhr Mills.--The buhr mill, because of the availability of plates or buhrs having machined teeth of various sizes, is used both as an intermediate and a fine grinder. Results of studies made in fine grinding corncob tailings (oversize materials from prior grinding and screening operations) with a buhr mill fitted with buhrs of various sizes are shown in table 17. Also included in the table are results of a series of grinding operations with progressively finer buhrs and without intervening removal of the fine products. In this latter series of studies the original feed material was aspirated crushed corncobs, such as used in studies with the attrition mill and the buhr mill with coarse buhrs. Results of the studies with the buhr mill showed that buhr mills grind to a rather close classification without high yields of fines smaller than No. 40. Overloading of a buhr mill should be avoided if maximum efficiency is to be obtained from the cutting edges of the intermeshing teeth. An excessive rate of feed causes buhrs or plates to spread so that particles between the plates will roll on one another and lose their angular shape. Furthermore, crowding of materials, particularly corncobs, into a buhr mill fitted with fine-tooth plates gives rise to undesirable or excessive heating.

Screening and Classifying

Screening and classifying are important unit operations in preparing ground agricultural residues for industrial use or for market. Specifications for ground products as to particle size, shape, density, and other characteristics require that separating and classifying equipment of the proper type be used. Screens for this purpose are generally of the oscillating or the vibrating types, although some processors are holding to the bulky trommels or reels used by flouring mills, particularly where abandoned flour milling equipment is used for processing operations.

Although a major proportion of screen surface of reels is never used, the rotating action of the reel accomplishes types of separations not possible with other screening equipment. For instance, the long sliver-like particles produced from corncobs by roller mill action separate according to thickness rather than length. The rotary action of the reels tends to cause particles to tumble and to pass on end through the screen. These particles, if passed over other types of screening equipment, would tend to remain parallel to the surface of the screen and would, consequently, remain above the screen.

The principles or methods upon which oscillating, gyratory, and vibrating sifters operate influence the efficiency of their performance. The particle shape and density as well as the relative proportions of the various fractions being separated also affect the efficiency of sifters. Some particles tend to lodge in screen openings because of peculiarities in particle shape. To correct this condition, changes in the frequency and amplitude of vibration or oscillation, the angle of pitch, the size and position of eccentrics, or other variables may be required. The number and types of variables depend upon the manufacturer's design. Selection of a given type of sifter should be based on tests with materials to be screened. Some sifters are provided with devices said to aid in avoiding choking or blinding of the screen openings. In general, sifters of the types discussed provide the maximum in screen surface and capacity for the floor space they occupy.

Screen capacity and efficiency drops noticeably when screen openings approach No. 80 or smaller. Because of difficulty in properly classifying materials of this fineness, some form of an aspirator classifier is generally used. Separation then takes place because of differences in size and weight of the individual particles.

A simple aspirating device can be made from an ordinary blower fan with the suction so arranged that the draft will remove small or lightweight particles from heavier coarser material. Such a device, with several modifications, has been used in cob-processing plants for the removal of husks, beeswing, pith, and chaff from the woody portion of cobs after the cobs have been crushed in a hammer mill.

However, for classifying the finely ground products, machines designed for the job are available and are preferable. These units uniformly distribute the material to be separated into an air stream which carries the small, light particles away from the larger heavier pieces. Damper adjustment, fan sizes, fan speeds, number and arrangement of whizzer blades, and other factors are the various means used for controlling the separation. Units of this general description have been very efficient in classifying flours as fine as No. 200 and No. 325.

Conveyors, Cyclones. Dust Collecting

Material handling becomes a problem in most types of processing plants. The complexity of any conveying system will depend upon the nature of the materials being handled, the conditions under which the materials accumulate, and the points to which the materials must be conveyed.

Belt conveyors with or without cleats often provide the simplest trouble-free means for moving materials from one point to another at the same level or where the difference in elevation (angular) is not too great. Where materials have to be elevated a considerable height, greater economy in space used can be realized by using bucket elevators instead of long inclined belt conveyors. The former are comparable to a belt conveyor to which a number of rectangular buckets have been attached. Use of the buckets makes it possible to raise materials at an angle of 90 degrees instead of at the lower angles necessary with belt conveyors.

Screw conveyors are large screws or spiral ribbons encased in pipe or tubing of appropriate size. For each revolution of the screw, material is advanced a distance equivalent to the lead of the screw. Direction of travel is no problem because movement of materials is by positive displacement. Screw conveyors have their limitations, however, just as do all pieces of equipment. Crushed corncob material containing appreciable quantities of husks will cause difficulty. The husks tend to wind around the bearings at the ends of the screws and cause binding.

Pneumatic conveying and collecting systems can be employed advantageously. The essential features of a pneumatic system are the blower, the piping, and the cyclone or collector. Although the entrance and exit ends of such systems are open to the atmosphere, the portion between the blower and the extremities of the cyclone

are under sufficient pressure that joints in the piping must be dust tight. The internal pressure of such a system will depend, too, on the height to which material is to be elevated. Cyclone collectors are, in a sense, space-savers because they can most frequently be located on the roofs of the structures they service. A reasonable amount of engineering data for design purposes is available in handbooks, reference books, and other literature (20, 34, 37). It is advisable to let the equipment manufacturer design the cyclone collectors to meet the requirements of the individual plant.

Drying

The necessity for artificial drying before or during processing is determined by the nature or condition of the original raw material, the characteristics required in the products, and cost considerations. Drying to suitable moisture content by natural means often can be accomplished through storage under appropriate conditions. In processing corncobs both methods of drying are used with apparent success. Where dryers are used in the systems, corncobs of any reasonable moisture content may be processed as received. However, where drying is by natural means in open-type cribs or storage structures, as already described (page 8), ample time must be allowed for loss of moisture to values appropriate for processing. Normally, a period of 3 to 4 months is adequate.

Where materials must be partially dried before or during processing, it is generally preferable to start with crushed or ground materials because of the greater surface area exposed to evaporation. The driers employed by processors have been (a) direct-fired by the hot gases of combustion and (b) indirect-fired or steam heated. The fuel often has been refuse from processing operations.

Drying equipment should be selected only after consultations with reputable manufacturers, engineers, and builders. In any event the equipment must be of the continuous type. Drying and pneumatic conveying can be combined by the use of hot flue gases as the conveying medium. For instance, when flue gases are used in the pneumatic system of an attrition or hammer mill, the temperature of the vapors issuing from the vent of the cyclone is indicative of the dryness of the materials in the system. That is, if the temperature of exhaust vapors can be maintained above 212° F., essentially no moisture remains in the finely ground materials. A sample of flour from leached pecan shells, dried by this method and analyzed by a commercial testing laboratory, contained about 1.25 percent of moisture¹⁰.

Reference to any of the tables on experimental grinding in which the effect of moisture was observed shows in all cases that greater ease in grinding and consequently greater mill capacities resulted from decreases in moisture content of the materials

¹⁰ Private communication.

ground. In the case of corncobs, where grinding is by impact or by attrition, the product increases in density with the higher moisture content in the feed material. A striking example of the effect of drying of corncobs on the character of the product from the hammer mill is shown by pellet or "buckshot" formation. With corncobs of 17 percent moisture content, "buckshot" formed inside the hammer mill when the screen had 1/4-inch diameter perforations. When these same corncobs were dried to 3.3 percent they could be ground in the same hammer mill with no "buckshot" formation whatsoever.

Miscellaneous

MAGNETIC SEPARATORS

Removal of ferrous metal from raw materials and products is essential, not only as a means for maintaining quality in the products, but also as a means for reducing operating expenses.

Depending upon its size, tramp metal can cause considerable trouble in processing equipment. Damaged hammer-mill screens, broken buhrs, and fires are a few of the hazards that may be encountered when tramp ferrous metal gets into a grinding system.

Three types of magnetic separators have proved practical in cob and shell processing plants: (a) The flush or plate type normally installed on inclines; (b) the grid type which can be installed in a floor or vertical chute; and (c) the pulley or drum type which is used in conjunction with belt conveyors. The third type is self-cleaning because the tramp iron picked up by the magnet is actually held on the surface of the belt running over the pulley. When the metal has moved beyond the magnetic field the metal drops from the bottom side of the belt. The kinds of magnetic separators to install in a processing plant are entirely dependent upon the type and arrangement of the principal equipment.

SURGE BINS

Judicious use of surge bins in process equipment lines is advantageous in maintaining smooth operations of a plant. However, surge bins should not be oversize to avoid excessive heating of materials. All surge bins should be emptied before operations cease at the end of a day. This is an important precautionary measure for avoiding fire in the processing plant.

MECHANICAL MAINTENANCE

Regardless of the apparent smooth operation of a grinding plant, complete inspection of all equipment should be made at frequent, regularly scheduled intervals. This does not eliminate the need for constant vigilance while the plant is operating. Worn hammers, plates, buhrs, screens, and similar items can be replaced during these inspection periods. Because the life of these items varies, it is seldom that replacement of more than one item will occur at a time. Equipment life for parts subject to wear is often expressed in terms of 500 to 1,000 tons or more of material processed. Thus it becomes a simple matter to approximate equipment life in terms of days or weeks of plant operation.

Lubrication is an important phase of proper maintenance. Manufacturers' recommendations should be followed in order to avoid conditions of excessive or insufficient lubrication, and a definite lubrication schedule should be put into force. If abnormally dusty conditions exist it may be necessary to provide some protection for bearings and journals since dust in these parts will increase the lubrication problem, in some cases with eventual loss of the bearings. Overloading of equipment beyond manufacturers' recommendations is unwise because of the unwarranted load on the bearings. Even the best lubrication practice cannot compensate for such a condition. The high maintenance cost in some cob-processing plants is attributable directly to overloading of equipment. In some instances, increasing the power delivered to a machine has made overloading possible.

PACKAGING AND STORAGE

Bagging, weighing, and finish product storage are essential to proper merchandising. Only certain products, such as cattle feed base, litter, and mulch from corn-cobs, can be merchandised in bulk in car or truck lots. The most practical method of packaging appears to be the use of multiwalled paper bags which can be sealed by a simple twist of a wire loop. Such a closure makes reuse of the bags possible. Package sizes of 40 or 50 pounds net weight are normal in the trade, although dense shell products are put up in packages of 80 and 100 pounds. To reduce labor, filling of bags and weighing should be made as simple as possible; flow of materials into a bag should be controlled by a weighing scale on which the bag rests; sealing and moving filled bags to a conveyor can be done manually. A simple roll conveyor will carry sealed bags to the shipping or storage area. For details in meeting the individual plant problem, equipment manufacturers are in the best position to provide recommendations.

Because some products do not accumulate daily in quantities sufficient for immediate shipment to consumers, appropriate storage facilities should be provided. Likewise, the market demands for products fluctuate and storage must be provided for slower moving items. The amount of the products to be stored is dependent to a large extent on aggressiveness in merchandising, or in moving the various grades in proportion to their yields. Storage facilities should be separated and isolated from the structure in which grinding and classifying are done.

FIRE PROTECTION AND EXPLOSIONS

Very frequently plants for processing agricultural residues are located in rural areas where fire protection is far from adequate. It is imperative that the operator understand the sources of fire and the precautionary and protective measures that should be taken to avoid it.

Static Electricity

Static electricity accumulates whenever non-conductors or insulating materials such as leather and rubber belting move over pulleys at relatively high speeds. Static becomes very evident when large sparks travel the gap from belting to a grounded portion of the equipment. All equipment should be thoroughly grounded and static dissipating devices should be used to eliminate spark production. Discharge of sparks in dusty atmospheres has often been the cause of dust explosions.

Electrical Fires

Fires of electrical origin are usually traceable to faulty maintenance and poor housekeeping. Because many processing plants are located in rural areas, building codes and regulations are sometimes overlooked or disregarded. The same codes and precautionary measures should be observed as though the plant were located in the heart of a large city. Too frequently "temporary" wiring installations become permanent. Portable cables and wiring are often subject to abuse by being in water, oil, or grease, and by being walked and trucked on. Insulation deteriorates rapidly under such conditions. Overloading of motors contributes to accelerated deterioration of insulation. Ammeters installed in motor circuits aid immensely in preventing build-up of overloads. Ammeter readings are useful, too, when duplication of operating conditions is desired.

Excessive lubrication of motors may become a menace. Dust and dirt accumulating about a motor contribute to overheating, worn bearings, and possible burnout. Non-aqueous or dry-type chemical (carbon dioxide) extinguishers should be kept handy for use near electrical equipment as a precaution in the event of fire.

Available Water and Steam

Adequate amounts of water at processing plants should be readily available in the event of fire. Need for water in combatting a fire is inversely proportional to the effectiveness of the plant maintenance and housecleaning program. Continuous removal of dust as it tends to accumulate about the plant will limit the areas in which fires can flash or explosions take place.

Table 18.- *Ratings¹ of explosibility of some dusts² based on averages of classes in regard to maximum pressure, average rate of pressure rise, and maximum rate of pressure rise³*

Material	Concentration of 100 milligrams per liter ⁴		Concentration of 500 milligrams per liter ⁴		Average for both concentrations	
	Group : Rating		Group : Rating		Group : Rating	
Alfalfa	4	33	4	37	4	35
Bituminous coal	8	73	6	57	7	65
Cedar wood	7	67	7	60	7	63
Cellulose	10	93	9	87	10	90
Corn dust	8	70	8	70	8	70
Cornstalk	6	53	7	63	6	58
Cornstarch	7	63	8	77	8	70
Fir	5	40	5	43	5	42
Lycopodium	10	100	5	47	8	73
Oat dust from dry kilns	7	67	8	73	8	70
Peanut hull	3	27	4	37	4	32
Redwood	8	73	7	63	7	68
White Pine	7	60	6	50	6	55

¹ See table 19 for basis of rating or classification.

² All dust passed a No. 200 U.S. Standard sieve and had been dried 4 hours under vacuum at 70° C.

³ Edwards, P. W., and Leinbach, L. R. Explosibility of Agricultural and other Dusts as Indicated by Maximum Pressure and Rates of Pressure Rise. U.S.D.A. Tech. Bulletin No. 490, p. 24, October 1935.

⁴ Concentrations of 100 mg. and 500 mg. per liter are equivalent to 100 oz. and 500 oz. per 1,000 cu. ft., respectively.

Maximum explosibility = 100; minimum explosibility = 0.

Table 19.-Classification of explosive dusts on the basis of time-pressure data¹

Class No. ²	100 milligrams per liter			500 milligrams per liter		
	Rate of pressure rise			Rate of pressure rise		
	Maximum pressure:			Maximum pressure:		
	Average		Maximum	Average		Maximum
	P.s.i.	P.s.i./sec.	P.s.i./sec.	P.s.i.	P.s.i./sec.	P.s.i./sec.
1	3-5	19-51	25-108	3-7	20-66	103-232
2	6-8	52-84	109-192	8-12	67-113	233-362
3	9-11	85-117	193-276	13-17	114-160	363-492
4	12-14	118-150	277-360	18-22	161-207	493-622
5	15-17	151-183	361-444	23-27	208-254	623-752
6	18-20	184-216	445-528	28-32	255-301	753-882
7	21-23	217-249	529-612	33-37	302-348	883-1,012
8	24-26	250-282	613-696	38-42	349-395	1,013-1,142
9	27-29	283-315	697-780	43-47	396-442	1,143-1,272
10	30-33	316-348	781-864	48-52	443-489	1,273-1,402

¹ Edwards, P. W., and Leinbach, L. R. Explosibility of Agricultural and other Dusts as Indicated by Maximum Pressure and Rates of Pressure Rise. U.S.D.A. Tech. Bulletin No. 490, p. 17. 1935.

² Explosibility classification of dusts increases from 1 to 10, class 10 indicating maximum explosibility.

Sprinkler systems installed in grinding plants afford good protection against fires. Fire insurance rates are reduced considerably for plants in which such systems are used. Where sprinklers are used, it is necessary to provide heat to prevent freezing during the winter months.

The feasibility of using steam as a fire preventative is dependent upon the type of the grinding equipment in use. In grinding many agricultural residues considerable heat is generated by friction and the products tend to become dry. With the dryness and agitation of the particles, static electricity builds up. These conditions, particularly in the fine grinding of materials, are readily corrected by addition of a small amount of water vapor or steam into the grinding systems. When sufficient water vapor is present to dispel the electrical charge, almost enough moisture will be present to prevent burning or smoldering of the ground material. Prevention of fires in grinding and classifying systems by means of steam is claimed in a patent granted to Ayres (9).

Dust Explosions

Dust explosions and fires have always been associated with any processing operation in which quantities of dusts from combustible materials are formed. Price and Brown in their book, "Dust Explosions" (35) discuss the several factors influencing the explosibility of dusts. In processing agricultural residues the more important factors are (a) moisture content, and (b) particle size. Dry organic materials are more susceptible to ignition than moist materials. Explosibility of a material increases with a decrease in particle size; the finer the dust the more readily an explosion can occur.

During an explosive reaction the rate of pressure rise is the rate at which the destructive forces develop. The greater the rate, the greater the destructive force. This force, if not released through vents or openings, can destroy the structure within which the reaction takes place. Brown and Hanson (12) have shown the relationship between maximum pressure developed during burning and the vent area required to release such pressure. So that one may appreciate the forces that develop when various dusts are exploded, explosibility ratings based on maximum pressures and rates of pressure rise as determined by Edwards and Leinbach (22) are presented in table 18. To show the basis for the classes or groups, time-pressure data are presented in table 19. Although data are not yet available on explosibility of the agricultural residues considered in this bulletin, it is possible to make some approximations. In explosibility, agricultural residue dusts might be considered comparable to the dusts of corn, cornstarch, and oats. The latter group of materials appears in class 8 with a rating of 70, as reported by Edwards and Leinbach (tables 18 and 19). It seems unlikely that the dusts of the residues involved will have explosive characteristics exceeding those of the materials mentioned above.

As another means for approximating the explosive hazards of a number of dusts, Wheeler (39) investigated their ignition temperatures. Ignition temperatures for some of these dusts are shown in table 20. The values are far in excess of any temperatures reported for the interiors of grinders or mills during continuous operation.

Table 20.- *Ignition temperatures of some dusts when heated instantaneously*¹

Material (percent finer than No. 200)	Heating small portion of cloud	Heating of entire cloud
	°C.	°C.
Wood flour	985	610
Sawdust, 20 percent	970	635
Offal grinding bran, 75 percent	980	640
Sugar, 50 percent	805	540
Starch, 80 percent	1,035	630
Oat husk, 90 percent	990	620
Flour, 90 percent	1,060	650
Corn flour, 90 percent	1,060	620

¹ Wheeler, R. V. Report Inflammability and Capacity for Transmitting Explosions of Carbonaceous Dusts Liable to be Generated on Premises under Factory and Workshop Act. Engineering 95: 606-607. 1912; presented also in Dust Explosions. Natl. Fire Protec. Assoc. Boston. pp. 10-17. 1922.

Approximately 10 pounds of coal dust or 7 pounds of starch dust is sufficient quantity of dust to form an explosive cloud in a room 20 feet by 25 feet by 10 feet (5,000 cubic feet). The requirements for dusts from agricultural residues should be of similar proportions. Cooperative work for evaluation of the flammability and explosibility of dusts from agricultural residues is being conducted by the U. S. Bureau of Mines.

Recently Cotton (19) reported on the development of a new method for evaluating dusts not only on a laboratory scale but also full scale. Cotton claims that it is possible to evaluate dusts according to ventability, dispersibility, ignitibility, and explosive concentration range as well as to predict probable damage to structures.

As mentioned earlier, low-pressure steam introduced into the pneumatic collecting systems from the fine grinders provides excellent control over the dust explosion hazard. This method has proved very satisfactory at the Northern Laboratory. Sufficient but not excessive moisture is introduced into the system by allowing the suction of the pneumatic system to pull the steam cloud into the ducts. This moisture is removed easily with the air exhausted from the stack of the cyclone. Considerable heat is absorbed by materials during grinding and this heat is important in the drying of the ground products. Evaporation of moisture from the surface of the particles tends to lower the temperature of the products.

The danger from undetected smoldering in finely ground material can be curtailed or limited by arranging an isolated storage for the products of one day's operation. In this way only a small portion of the plant's production may be lost in the event of undetected fire or smoldering in the materials.

Recommendations of the National Fire Protection Association (3, 4) for construction and operation of processing plants should be consulted and followed to minimize the possibilities of dust explosions and fires.

TRAMP METAL AND STONES

Both tramp metal and stones may be the cause of dust explosions and fires during grinding operations. The use of various types of magnets in removing tramp iron has already been discussed. Magnets provide economical insurance not only against explosions and fires but also against material damage to plant facilities.

Stones, while not responding to magnets, can be removed by some types of separators based on differences in specific gravity. Vibrating low-angle inclines (vibratory feeders) are effective separators because operating conditions can be adjusted so that the agricultural residue can be caused to move up the incline while the stones are discharged from the bottom. Pneumatic conveying systems are frequently used as a means for moving agricultural residues, corn cobs for example, without picking up stones and rocks.

PLANT CLEANING EQUIPMENT

Equipment for routine cleaning of a processing plant should include the portable, industrial vacuum cleaner with accessories so that hard-to-reach spots can be cleaned without trouble. Compressed air should *never* be used for cleaning when the plant is operating, when unprotected lamps are burning, or when open flames, including cigars or cigarettes, are within the building. As a matter of good practice, compressed air should not be used for cleaning purposes because of conditions which lead to dust explosions.

PLANT LOCATION

It is desirable to locate a processing plant within the area in which the agricultural residues are produced. This tends to lower the expense of collection and transportation to the processing plant. Any area for which a processing plant is contemplated should be able to provide a minimum of 5,000 tons annually of the agricultural residue. That quantity is sufficient when operation of only one shift per day is considered. The radius within which this 5,000 tons must be available is variable, depending upon the value of the residue concerned. If corncobs are worth only \$3 per ton at processing plants the haul must be short, about 25 miles maximum. However, if the value of cobs is increased to \$10 or more as in the case of nut shells, the residues can be economically transported much longer distances.

A processing plant, regardless of how efficient its operation, must be located so that the products can be shipped conveniently to the points of consumption. Either rail or truck transportation, and preferably both, should be readily available. Unless a processing plant can get its products to the market without difficulty, the operations are not apt to be profitable.

PLANT LAYOUT - MACHINERY FLOW DIAGRAM

No single arrangement of equipment is satisfactory for processing all types of agricultural residues. Each material presents its own problem in regard to cleaning, fractionating of constituents, and classifying the products. Figure 18 presents a schematic flow diagram for three different types of grinders or mills. The plan is very general, but is intended to convey to the reader some of the factors and details that must be considered in establishing a dry-grinding plant. Certain factors must be borne in mind in designing a layout of equipment and buildings: (a) Processing plant should be designed for ease and speed in cleaning; (b) raw material and product storage structures should be isolated from processing operations. This latter consideration is a precautionary measure for limiting losses in the event of fire in the grinding plant.

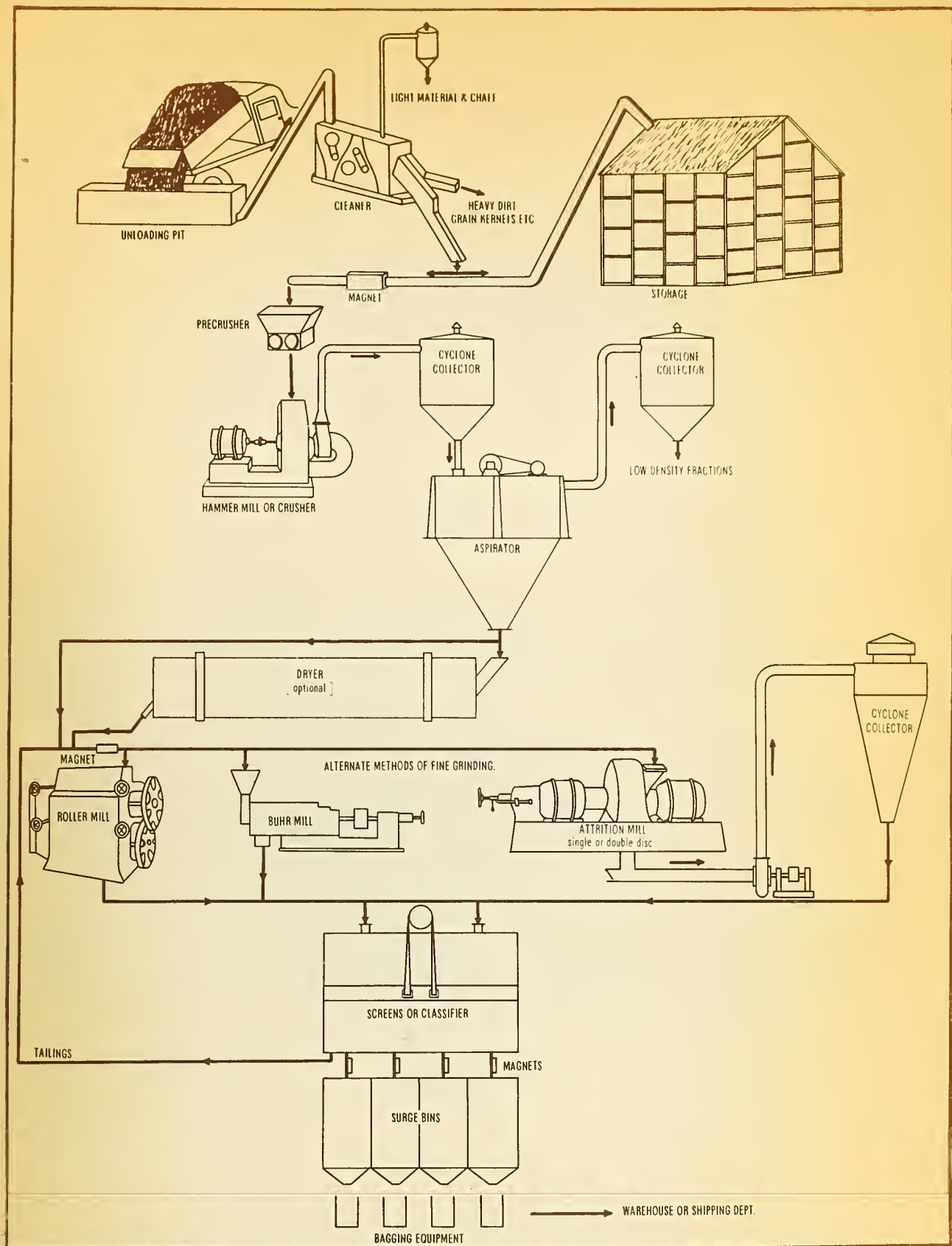


Figure 18.-- Flow diagram showing mechanical processing steps in the grinding of agricultural residues.

CAPITAL COSTS OF PROCESSING PLANTS

For a processing plant capable of producing 1 to 1-1/2 ton of finished materials per hour, the cost varies considerably depending upon the type of processing equipment selected. Under conditions existing in September 1951, the cost of equipment and accessories approximates \$25,000 to \$75,000 at the points of manufacture. Transportation, installation, and buildings may amount to \$50,000 to \$75,000. Thus, a sizeable investment is necessary for properly financing a processing plant. Some operators have reduced the initial investment required by use of second-hand equipment. Unless an operator is thoroughly experienced in evaluating used equipment, this practice is to be discouraged because of the many difficulties that may be encountered. Cost of buildings is a factor that can be determined only after a thorough consideration of space requirements and year-round weather conditions.

LABOR AND MANAGEMENT EXPENSE

The following operations or steps require labor: (a) Unloading and storage; (b) grinding and mechanical maintenance; (c) bagging; (d) shipping and storage; and (e) plant cleaning. Some operations will not require an employee's attention all the time, so the individual becomes available for other duties during a portion of the day. For example, a well-planned plant, 1 1/2 tons per hour capacity, can operate smoothly at present with a crew of only five men.

Management and sales personnel must also be considered as an operating expense of a plant. Some time must be charged to procurement, not only of the agricultural residues but also of replacement parts, shipping containers, and so forth. Management must also assume the responsibility of inspecting and checking the products periodically in order that specifications will be met.

Power for operation of processing equipment is one of the largest single costs in operating processing plants. Although both water and diesel engine power have been used in grinding operations, electric power has proved more suitable. Connected loads of 150 to 200 horsepower are not unusual in processing residues, therefore, plants should be located as near as possible to electric power lines of adequate size.

PRODUCTS

Quality Control

Product quality is a necessity and the lack of quality or failure to meet set standards does constitute a threat to successful merchandising. The hazard exhibits itself as: (a) Contaminants (metallic inclusions, ground stone) or other foreign substances; (b) as products from which proper constituent separation has not been made; (c) improper classification according to size; and (d) as products from improper grinding methods.

Metal slivers, chips or fragments from mill plates, rolls, hammers and so forth, appearing in the final products can cause untold damage when the soft grits are used in air-blast cleaning, in tumbling barrel finishing, and in similar operations. Methods for control or removal of contaminants such as metals and stones have already been discussed. Improper separation of constituents can be readily corrected through proper adjustment of machines. This type of separation often shows a two-way profit. Lathrop claims products of improved characteristics by removing tannin-bearing constituents from pecan shells following a simple break in a hammer mill (26). A user of processed agricultural residues has his reasons for specifying a particular classified material. Deviation from his specifications might change the character of his products or some operation in his plant.

Product Use and Specifications

The manner in which agricultural residues are to be used exerts considerable influence upon the type of processing operation. A striking example of this is found with corncob particles intended for use in cleaning by the soft-grit or air-blast method. Blast cleaning of mechanical items such as gasoline engine parts requires soft grits that are reasonably hard and durable. Soft grits of this description can be prepared without difficulty by grinding crushed corncobs in an attrition mill. Under proper conditions the cob material is compacted slightly while being cut. However, for cleaning electrical insulation as in large generators, softer, lower density grits are required. These can be obtained by changes in operation of the attrition mill or by the use of other types of mills such as the buhr mill or the roller mill.

The character of the raw material before grinding determines the type of markets or fields of application that can be exploited. Thus, hard shells of nuts or of fruit pits will not be processed for use where absorbency is the required characteristic. Instead, corncobs may be processed in buhr mills, roller mills, or attrition mills in such a manner that the absorbency of the product will be actually greater than that of the original cobs. The absorbent surface of the corncob particle is increased without any appreciable increase in the density. This Laboratory has published considerable information regarding the use of agricultural residues in plastics, plywood adhesives, soft-grit cleaning, soap manufacture, and other applications (14, 15, 16, 17, 18, 28, 40, 41).

When sales of processed agricultural residues are made directly to the consumer, any desired changes in character of the product or in specifications can be made in a relatively short time. In the event that questions or information must pass through a third party, for example, a distributor or jobber, it is possible that the processor never receives the information essential for making desirable changes or adjustments, with a consequent loss of sales.

Value of Products

Superior properties of a material are ample reasons for establishing prices comparable to or greater than those for competing materials. Many of the products produced from agricultural residues are doing jobs that *cannot* be performed so satisfactorily with other material. Typical of this situation is the carbon removal and cleaning of aircraft engine parts by the soft-grit blast method in which grits prepared from corncobs or shells of nuts and fruit pits are used in conventional air-blast cleaning equipment. No masking of surfaces is required as when sand is used because soft grits cause no damage to the surface nor do they cause any dimensional change. Likewise, use of the soft grits eliminates the use of inflammable and toxic solvents in cleaning and thereby reduces the hazards to personnel and property. Several instances of serious illness and some deaths from improper use of carbon tetrachloride and other chlorinated solvents have been reported (11, 23, 32).

The monetary value of processed agricultural residues varies considerably--depending upon the material, the size classification, and quality--roughly from \$10 per ton for coarsely crushed corncobs to more than \$100 per ton for certain nut shell products. In general, the price of all ground corncob products probably averages about \$50 per ton f.o.b. the processing plants.

MERCHANDISING AND ADVERTISING

Much of the success in custom grinding of agricultural residues depends upon proper methods of promoting sales or merchandising all the products.

When the trade groups or names of industrial organizations who are users or potential users of processed agricultural residues are known, literature with appropriate samples may be sent out to acquaint the organizations with the processor and the type and quality of his products. This type of advertising should be followed by further correspondence and personal contacts. Personal contacts permit discussions of the actual applications or problems involved, the specifications, and the advantages and disadvantages of the materials. Personal contacts may also permit a processor or his representative to conduct actual tests or demonstrations in the customer's plant in order to improve operations or to correct past operational difficulties.

Advertising in representative trade journals is an essential means for keeping the name of a processor and of his products before the consuming industries. This type of advertising reaches many small consumers whom it would be almost impossible to contact by direct mail. While selling through distributors simplifies the bookkeeping, billing, and shipping problems for the processor, much of the personal contact between producer and consumer may otherwise be lost. The value of personal contacts has been discussed already under Product Use and Specifications.

Processors should be alert in developing improvements in processing and in developing new applications for the products.

SUMMARY

Mechanical processing of agricultural residues for agricultural and industrial purposes can be accomplished with profit and with a minimum of operational hazards. To achieve this goal the plant should be well engineered for processing the specific residues involved and the line of products to be prepared. At all times the principles as stated by Lathrop and Shollenberger (29) must be kept in mind and observed.

Mechanical processing also has proved its value to elevator operators, shellers, fruit canners, and farmers in removing accumulations of hazardous combustible materials as well as in removing the nuisance associated with the decomposition of nut fragments, fruit pulps, and ligno-cellulosic materials.

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LITERATURE CITED

1. Anonymous
1946. NEW SYNTHETIC LIQUID FUEL PLANT IN OPERATION. U. S. Dept. Agr. Press Release 2347-46.
2. -----
1948. FEEDING CORN COBS. The Farm Quarterly. Autumn: 76-80, 140, 141, 143.
3. -----
1948. STANDARDS FOR THE PREVENTION OF DUST EXPLOSIONS IN STARCH FACTORIES, TERMINAL GRAIN ELEVATORS, FLOUR AND FEED MILLS. NBFU Pamphlet No. 61. 40 pp. National Board of Fire Underwriters. New York.
4. -----
1949. STANDARDS ON THE FUNDAMENTAL PRINCIPLES FOR THE PREVENTION OF DUST EXPLOSIONS IN INDUSTRIAL PLANTS. NBFU Pamphlet No. 63. 10 pp. National Board of Fire Underwriters. New York.
5. -----
1951. ANNUAL SUMMARY--ACREAGE, YIELD, AND PRODUCTION OF PRINCIPAL CROPS. U. S. Dept. Agr. Bur. Agr. Econ. Crop Reporting Board. p. 52.
6. -----
1951. CORNELL OPPOSES USE OF BUILT UP LITTER FOR STARTING BABY CHICKS. Feed-stuffs 23 (41): 36. Article reprinted from report from Cornell University by P. B. Levine.
7. -----
1951. PURDUE UNIVERSITY TESTS ROUGHAGE RATIONS FOR STEERS. Agricultural News Letter (Du Pont) 19 (1): 3-8.
8. -----
1948. THERE'S GOLD IN THAT COB PILE! 14 pp. Garst and Thomas Hybrid Corn Co. Coon Rapids, Iowa.
9. Ayers, J. W.
1951. FIRE-AVOIDING GRINDING AND CLASSIFYING SYSTEM AND PROCESS. (U. S. Patent No. 2,554,450) U. S. Patent Office, Off. Gaz. 646: 1368.
10. Beeson, W. M.
1950. CORN COBS IN CATTLE FEEDS. Grain and Feed Journals 104 (2): 24-25.
11. Bell, A. P., and Mitchell, W. A.
1949. CARBON TETRACHLORIDE CAUSES TWO DEATHS IN INDUSTRY. Industrial Hygiene Newsletter, U. S. Public Health Service 9 (8): 4, 13; abstract in Chemical Abstracts 43: 7605.
12. Brown, H. R., and Hanson, R. L.
1933. VENTING DUST EXPLOSIONS. National Fire Protection Association Quarterly 26: 328-341. illus.

13. Chambers, D. H.
1950. FLASH REMOVAL BY NEW PROCESS. Modern Plastics 27 (9): 91, 94.
14. Clark, T. F.
1948. NEW ABRASIVE FOR HAND SOAPS. Soap and Sanitary Chemicals 24 (8): 41, 149, 151.
15. -----
1949. AGRICULTURAL RESIDUES IN PLASTICS. PART III. EVALUATION OF RESIDUE FLOURS AS FILLERS IN THERMOSETTING PHENOLICS. Modern Plastics 26 (12): 111-116, 164-165.
16. ----- and Aronovsky, S. I.
1944. AGRICULTURAL RESIDUES, A COMPARATIVE STUDY. Modern Plastics 22 (4): 162-164, 198.
17. ----- and Lathrop, E. C.
1950. SOFT GRITS PROVIDE LOW COST METHOD FOR BLAST CLEANING METALS. Materials and Methods 31 (5): 67-69.
18. -----, Williamson, R. V., and Lathrop, E. C.
1945. AGRICULTURAL RESIDUES IN PLASTICS. PART I. AGRICULTURAL RESIDUE FLOURS. Modern Plastics 23 (2): 158-160, 214, 216, 217.
19. Cotton, P. E.
1951. NEW TEST APPARATUS FOR DUST EXPLOSIONS. National Fire Protection Assoc. Quarterly 45 (2): 157-164.
20. Dedrick, B. W.
1924. PRACTICAL MILLING. pp. 292-5. National Miller. Chicago.
21. Dunning, J. W., Winter, P., and Dallas, D.
1948. THE STORAGE OF CORNCOBS AND OTHER AGRICULTURAL RESIDUES FOR INDUSTRIAL USE. Agricultural Engineering 29 (1): 11-13, 17.
22. Edwards, P. W., and Leinbach, L. R.
1935. EXPLOSIBILITY OF AGRICULTURAL AND OTHER DUSTS AS INDICATED BY MAXIMUM PRESSURE AND RATES OF PRESSURE RISE. U. S. Dept. Agr. Tech. Bull. No. 490. 24 pp.
23. Gray, I.
1947. CARBON TETRACHLORIDE POISONING. [Report of seven cases with two deaths.] New York State Journal of Medicine 47: 2311-2315; abstract in Chemical Abstracts 43: 3106.
24. Halbrook, E. R., Winter, A. R., and Sutton, T. S.
1950. BUILT-UP POULTRY-HOUSE LITTER AS A GROWTH-PROMOTING SUPPLEMENT FOR CHICKS ON AN ALL-VEGETABLE VITAMIN B₁₂-DEFICIENT DIET. Science 112: 308-309.
25. Harbin, C. E.
1951. MOST DUST EXPLOSIONS COULD BE PREVENTED. Grain and Feed Journal 107 (9): 15-16.